



# Research and Development

SOURCE SAMPLING

FINE PARTICULATE MATTER:

WOOD-FIRED INDUSTRIAL BOILER

## Prepared for

**Office of Air Quality Planning and Standards**

## Prepared by

National Risk Management  
Research Laboratory  
Research Triangle Park, NC 27711

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National Risk Management Research Laboratory

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# **Source Sampling Fine Particulate Matter:**

## **Wood-Fired Industrial Boiler**

by

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## **Abstract**

Fine particulate matter of aerodynamic diameter 2.5  $\mu\text{m}$  or less (PM-2.5) has been implicated in adverse health effects, and a National Ambient Air Quality Standard for PM-2.5 has been promulgated (July 1997) by the U. S. Environmental Protection Agency. A national network of ambient monitoring stations has been established to assist states in determining areas which do not meet the ambient standard for PM-2.5. For such areas, it is important to determine the major sources of the PM-2.5 so states can devise and institute a control strategy to attain the ambient concentrations set by the standard.

One of the tools often used by states in apportioning ambient PM-2.5 to the sources is a source-receptor model. Such a model requires a knowledge of the PM-2.5 chemical composition emitted from each of the major sources contributing to the ambient PM-2.5 as well as the chemical composition of the PM-2.5 collected at the receptor (ambient monitoring) sites. This report provides such a profile for a wood-fired industrial boiler equipped with a multistage electrostatic precipitator control device. Along with the PM-2.5 emission profile, data are also provided for gas-phase emissions of several organic compounds. Data are provided in a format suitable for inclusion in the EPA source profile database, SPECIATE.

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## **Section 1**

### **Introduction**

In July, 1997, the U. S. Environmental Protection Agency (EPA) promulgated a new National Ambient Air Quality Standard (NAAQS) for ambient particulate matter (PM) of aerodynamic diameter 2.5  $\mu\text{m}$  or less (PM-2.5) and revised the existing standard for ambient particles of aerodynamic diameter 10  $\mu\text{m}$  or less (PM-10). The first steps in implementation of the new standard have been to deploy a network of ambient monitors and to collect the three years of data required for designation of areas as nonattainment or attainment of the new standard. This period also will give EPA time to review newer research on the observed correlation between ambient fine particulate matter and adverse human health effects.

In 1999, a national network of ambient monitoring stations was started under the overall guidance of the EPA's Office of Air Quality Planning and Standards (OAQPS) to assist the States in determining regulatory non-attainment areas and to develop State Implementation Plans (SIPs) to bring those areas into compliance with the law for PM-2.5 and revised PM-10 regulations. One component of the monitoring network will be a few (4-7) "Supersites:" i.e., regional airsheds in which intensive coordinated particulate matter-related research will be carried out in order to attain a better understanding of the links between source emissions and actual human dosages of fine particulate matter.

To support development of this better understanding, the Emissions Characterization and Prevention Branch (ECPB) of the Air Pollution Prevention and Control Division (APPCD) oversees research to characterize PM-2.5 emissions from specific source categories, develops chemical profiles of fine PM constituents from specific sources, and populates the OAQPS SPECIATE database with improved source profiles. Profiles in SPECIATE are used by receptor

modelers nationwide to conduct modeling analyses to identify specific sources of fine PM found in ambient air by the national network of ambient monitoring stations.

Previous development of source signatures at EPA have focused on analysis of elemental constituents which are usually condensed at stack sampling temperatures. To add improved analytical power to source signatures, ECPB and others are analyzing organic and elemental constituents. Due to very significant shifts in organic gas/particle phase partitioning as a function of temperature, there are large differences between profiles acquired by analysis of raw stack gas samples at stack temperature and those acquired by dilution sampling. Use of a dilution sampler cools the sample and provides additional residence time for developing a stable partitioning of semivolatile species at near-ambient temperatures. The dilution sampler gas/particle phase partitioning provides samples more representative of the fine PM collected by monitoring stations at ambient temperature, especially for the organic components.

This project focuses on updating and improving source emission profiles and emission rates for PM-2.5 with the dual aim of improving the quality of data used for dispersion and receptor modeling of ambient PM-2.5 and of providing quality emissions data for evaluation of risk management strategies. The program has concentrated its PM source sampling efforts on the sources and types of PM-2.5 where data are most lacking and needed, with a primary focus on the collection of fine particles emitted by combustion sources, both stationary and mobile.

## **Test Objectives**

The mission of the ECPB is to characterize source emissions and develop and evaluate ways to prevent those emissions. Source characterization as defined here includes the measurement of PM mass emission rates, source PM profiles (PM chemical composition and associated chemical mass emission rates), and emission rates of ambient aerosol precursors such as  $\text{SO}_x$ ,  $\text{NO}_x$ , and  $\text{NH}_3$ .

PM mass emission rates are used in emission inventories and as inputs to atmospheric dispersion models which yield estimates of ambient PM concentrations via considerations of atmospheric transport and transformation of emitted particles. Source characterization data are used in receptor models which enable apportionment of ambient concentrations of PM to the various sources which emitted the particles. The overall objective of this program is to update and improve source emission profiles and emission rates for PM-2.5 with the dual aim of improving the quality of data used for dispersion and receptor modeling of ambient PM-2.5 and of providing quality emissions data for evaluation of risk management strategies.

Source types for testing in this program were selected on the basis of the quantity of fine PM emitted by the source type as determined from emission inventories and on the basis of the quality of existing PM-2.5 source profiles for each source type. This report presents the results of testing one source type so selected, i.e., a wood-fired industrial boiler (Source Classification Code SCC 10200902) with the aim of acquiring a PM-2.5 emissions profile for source receptor modeling purposes.

## **Organization of Report**

This report is organized into five additional sections plus references and appendices. Section 2 provides the conclusions derived from the study results, and Section 3 describes the process operation and the test site. Section 4 outlines the experimental procedures used in the research, and Section 5 presents and discusses the study results. Section 6 presents the quality control/quality assurance procedures used in the research to ensure generation of high quality data.

## Section 2

### Conclusions

Both gas- and particle-phase emissions from the wood-fired boiler were measured. Values reported are for the composition of gas and particulate matter emissions following cooling and dilution of the boiler stack gas rather than the in-stack exhaust gas composition and may therefore be considered representative of the emissions in the exhaust plume near the stack. Diluted source emissions reported in this way are more appropriate than in-stack data for source-receptor models used for apportioning pollutants in the ambient air to the sources of the pollutants.

Mass emission rates for Speciated Nonmethane Organic Compounds and Carbonyl Compounds are shown in Table 2-1. An explanation for the observed significant difference

**Table 2-1. Mass Emission Rates for Nonmethane Organic Compounds and Carbonyl Compounds**

Parameter	Mass Emission Rate mg/kg Fuel	
	Day #1	Day #2
Speciated Nonmethane Organic Compounds	4.83	0.98
Total Nonmethane Organic Compounds (Speciated + Unspeciated)	7.50	1.85
Speciated Carbonyl Compounds	2.53	0.80
Total Carbonyl Compounds (Speciated + Unspeciated)	2.74	0.94
PM-2.5 mass	3.54	1.23

in emission rates of both gaseous and PM-2.5 emissions between the two test days could not be deduced with confidence. Both the boiler and sampling system operating parameters were essentially identical for both days. The only apparent variable which may have contributed to the difference was the nature of the chipped wood fuel itself since the fuel was selected from different locations in the large on-site wood chip storage pile during the two days of testing. However, only one composited wood waste sample from the storage pile was analyzed, so any significant differences in boiler feed between the two tests could not be determined.

Elemental and organic carbon content of the PM-2.5 collected on quartz filters was found to be highly dependent on whether an XAD-coated denuder was inserted in the sampling line prior to the filter. The purpose of the denuder was to remove gas-phase semivolatile organic compounds which otherwise might be adsorbed to the quartz filter, thereby resulting in a positive artifact to the particulate matter collected. Without the denuder, the amount of organic carbon found on the quartz filters was 2.6 times the amount found with the denuder, thus providing confirmatory evidence for a positive adsorption artifact. The relatively small amount of PM mass collected on these filters appears to render this adsorption artifact especially noticeable and the adsorbed gaseous organic compounds appear to be primarily responsible for a calculated mass balance of greater than 100 percent when the organic carbon value for the undenuded case is used.

Individual organic compounds comprising the organic carbon fraction of the PM-2.5 emissions consisted mostly of polynuclear aromatic hydrocarbons (PAHs), alkanes (>C15), alkanoic acids (>C8), and the iso- and anteiso-alkanes. Levoglucosan, a marker compound for biomass combustion, was found in the particulate matter but not in the relatively large amounts characteristic of open burning of biomass or wood stove combustion emissions. Resin acids (e.g., pimaric, isopimaric, and sandarapimaric acids) used as markers for softwood combustion and methoxyphenols used as markers for hardwood combustion were not found. Therefore, the organic compound emission profile for the wood-fired industrial boiler is very unlike profiles for residential wood-fired appliances (wood stoves and wood-burning fireplaces) and biomass open



burning. This observation is not unexpected since the combustion regimes are very different for the two types of sources and since the boiler particulate matter emissions in this case were controlled by a multi-stage electrostatic precipitator whereas residential wood-fired appliance emissions are typically uncontrolled. From this one stationary source test, no unique markers for source apportionment were identified.

Residential wood-fired appliances operate at much lower temperatures compared to industrial boilers, and the combustion process for wood stoves and fireplaces entails repeated cycling from an initial kindling phase through a final smoldering phase over the course of normal operation. Operation of an industrial boiler such as the one studied here involves charging the fuel at a fairly constant rate, and the combustion can be thought of as occurring in two stages: an initial stage in which the wood is gasified under pyrolysis conditions and a second stage in which the pyrolysis gases are essentially completely combusted at high temperature in the presence of excess air.

## **Section 3**

### **Methods and Materials**

#### **Description of the Testing Program**

A field test was conducted (August 8-9, 2000) at a wood-fired industrial boiler (SCC 10200902) equipped with an electrostatic precipitator control device, with quality control procedures implemented to obtain source emissions measurements of known quality. To simulate the behavior of fine particles as they enter the ambient atmosphere from an emissions source, dilution sampling was performed to cool, dilute, and collect gaseous and fine particulate emissions from the wood-fired industrial boiler. Gaseous and fine particulate material collected during the sampling was also characterized. ERG coordinated all field test activities; laboratory testing activities were divided between EPA and ERG according to the scheme shown in Table 3-1.

The objectives of the testing activities were to evaluate the sampling equipment and to characterize the fine particulate emissions from a wood-fired boiler equipped with an electrostatic precipitator. ERG performed source sampling to collect artifact-free, size-resolved particulate matter in a quantity and form sufficient to identify and quantify trace elements and organic compounds and to distinguish gas-phase and particle-phase organic compounds. Total particulate matter mass in the diluted and cooled emissions gas was size-resolved at the PM-10 and PM-2.5 cut points with the PM-2.5 fraction further continuously resolved down to 30 nm diameter using a Scanning Mobility Particle Sizer (SMPS). Fine particle emission profiles can be used in molecular marker-based source apportionment models, which have been shown to be powerful tools to study the source contributions to atmospheric fine particulate matter.

**Table 3-1. Sampling Medium Used for Collection of Samples, Analysis Performed, Analytical Method, and Responsible Laboratory**

<b>Sampling Medium</b>	<b>Analysis</b>	<b>Method</b>	<b>Laboratory</b>
Teflon® Filter	PM-2.5 mass	Gravimetric (GRAV)	EPA
Teflon® Filter	Elemental Analysis	X-ray fluorescence (XRF)	EPA
Teflon® Filter	Inorganic Ions	Ion Chromatography (IC)	EPA
Quartz Filter	Elemental Carbon/ Organic Carbon	Thermal-Optical Evolution (TOE)	EPA
Quartz filter XAD-4® denuder PUF	Organic species	Gas Chromatography/ Mass Spectrometry (GC/MS)	EPA
DNPH-impregnated silica gel tubes	Carbonyl compounds	High Performance Liquid Chromatography (HPLC) Method TO-11A	ERG
SUMMA® canisters	Air Toxics Speciated Nonmethane Organic Compounds	GC/MS Method TO-15 ERG Concurrent Analysis	ERG
Particle Size Analyzer	Particle Sizes	Ion mobility spectrometer	ERG

To assist in the characterization of the stationary source and to obtain chemical composition data representative of particle emissions after cooling and mixing with the atmosphere, ERG performed the following activities at the test site:

- Installed the pre-cleaned dilution sampling system, sample collection trains, and ancillary equipment at the field site without introduction of contaminants;
- Calibrated flow meters before and after sampling, monitoring and adjusting gas flows (as necessary) throughout the tests;

- Acquired process data for the test periods, including temperatures, pressures, flows, fuel consumption, etc.;
- Collected two sets of stationary source samples as prescribed in the Site-Specific Test Plan, including one set of field blanks;
- Determined the type of combustion fuel (gross characterization of wood waste material and any auxiliary fuel) and the rate of consumption during the source tests; and
- Recovered the dilution sampling unit and sample collection trains for analysis for specific parameters and return of the dilution sampling unit to EPA.

ERG collected integrated samples and performed whole air analysis of volatile organic compounds from SUMMA<sup>®</sup>-polished stainless steel canisters and gas-phase carbonyl compounds from 2,4-dinitrophenylhydrazine (DNPH)-impregnated silica gel cartridges, as well as evaluation of particle size distribution data collected. EPA was responsible for cleaning and transport of the dilution sampling system to the test site, for analysis of semivolatile organic compounds from XAD-4<sup>®</sup> denuders and polyurethane foam (PUF) sampling modules, and for characterization of the particle phase emissions and mass loading on quartz and Teflon<sup>®</sup> filters.

### ***Description of Test Equipment***

#### **Dilution Sampling System**

The dilution sampling system used in the source test was based on an original design by L. M. Hildemann (Hildemann et al., 1989), modified to incorporate more secure closure fittings and electronic controls. Automatic flow control and data acquisition capabilities were added to the dilution sampler to improve the ease of operation of the unit. A touchscreen interface connected to the main controller was used to monitor current conditions and allow setpoints to be entered into the system readily. A laptop computer was used for continuous monitoring of operating parameters and logging of the sampler operation.

ECPB built a state-of-the-art dilution sampler to deploy in the performance of this field testing effort. The dilution sampling system dilutes hot exhaust emissions with clean air to simulate atmospheric mixing and particle formation. Control of residence time, temperature, and pressure allows condensible organic compounds to adsorb onto fine particles as they might in ambient air. The sampler is also designed and fabricated to minimize any contamination of samples, especially organic compound contamination, and to have particle losses to the sampler walls of no more than approximately 7 percent.

Figure 3-1 shows a schematic diagram of the dilution sampling system and dilution air conditioning system. As shown, the dilution air conditioning system provides High Efficiency Particulate Arresting (HEPA) and activated carbon-filtered air. Acid gases (if present) will not be completely removed by the dilution air conditioning system, but the presence of acid gases can be monitored in the dilution tunnel immediately downstream of the dilution air inlet. The dilution air conditioning system can be modified to add a heater, cooler, and dehumidifier as needed. Cleaned dilution air enters the main body of the sampler downstream of the dilution air orifice meter.

The key zones of the dilution sampling system and their function are as follows:

***Sample Inlet Zone—***

*Stack Emissions Inlet:* designed to allow source exhaust gas to be sampled through an inlet cyclone separator to remove particles with nominal aerodynamic diameters  $> 10\ \mu\text{m}$ . The PM-10 cyclone prevents large particles from entering the sampler to plug or damage the equipment. Three ports are dedicated to sampling of the dilution air before it mixes with the source gas.

*Heated Inlet Line:* 3/4" heated stainless steel sampling probe draws source gas through a venturi meter into the main body of the sampler. Sample flow rate can be adjusted from 15-50 Lpm (typically 30 Lpm).

***Venturi Meter—***

Constructed of low carbon, very highly corrosion-resistant stainless steel; equipped for temperature and pressure measurement. Wrapped with heating coils

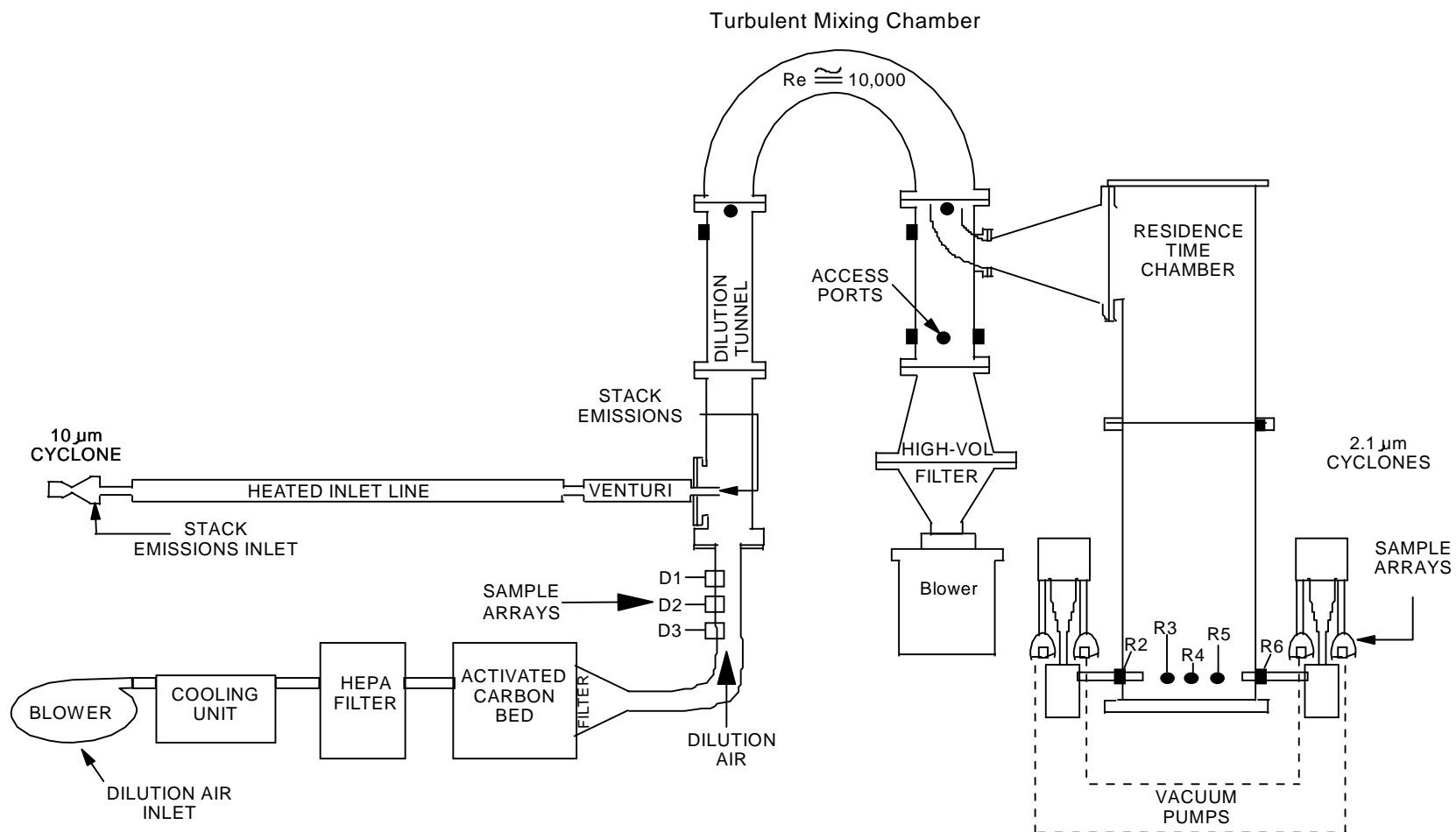


Figure 3-1. Diagram of the dilution sampler and dilution air conditioning system.

and insulated to maintain the same isothermal temperature as the inlet cyclone and inlet line.

### ***Turbulent Mixing Chamber—***

Consists of an Entrance Zone, U-Bend, and Exit Zone.

Inside diameter: 6 in., yielding a Reynolds number of ~10,000 at a flow rate of 1000 Lpm.

Dilution air enters the Mixing Chamber in the direction parallel to the flow.

Hot source emission gas enters the Chamber perpendicular to the dilution air flow, 4.5 in. downstream of the dilution air inlet.

The combined flow travels 38 in. before entering the U-bend.

After the Residence Chamber Transfer Line, the Mixing Chamber continues for 18 in., then expands to an in-line high-volume sampler filter holder. Collected particulate has not experienced time to equilibrate with the gas phase at the diluted condition.

Sample and instrumentation ports are installed on the Turbulent Mixing Chamber at various locations.

### ***Residence Time Chamber—***

The inlet line to the Residence Time Chamber expands from a 2 in. line (sized to provide a quasi-isokinetic transfer of sample gas from the Turbulent Mixing Chamber to the Residence Time Chamber at a flow rate of ~100 Lpm) within the Mixing Chamber to a 7 in. line at the wall of the Residence Chamber.

The flow rate is controlled by the total sample withdrawal from the bottom of the Residence Time Chamber and provides a 60-sec residence time in the Chamber.

Twelve ports are installed at the base of the Residence Time Chamber:

Nine ports for sample withdrawal

Three ports for instrumentation.

### ***Sample Collection Zone—***

Samples collected from the sample ports at the base of the Residence Time Chamber have experienced adequate residence time for the semivolatile organic compounds to re-partition between the gas phase and the particle phase.

Since it is very difficult to maintain both isokinetic sampling and a fixed cyclone size cut during most stack sampling operations, the inlet cyclone may be operated to provide a rough PM-10 cut while maintaining near-isokinetic sampling. The rough inlet size cut has minimal impact on sampling operations since the dilution sampling system is mainly used to collect fine particulate matter from combustion sources and the critical fine particle size cut is made at the

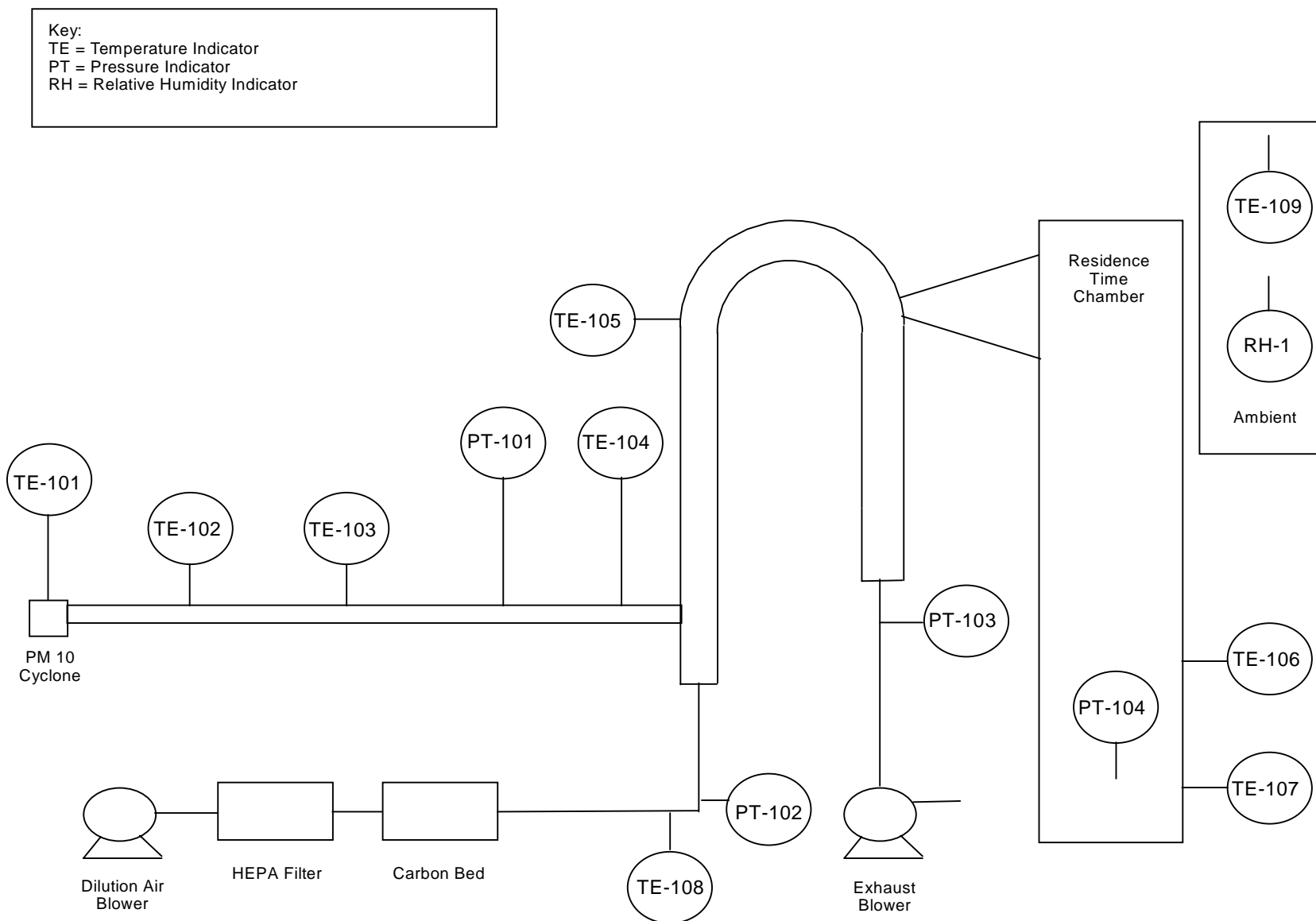
end of the Residence Time Chamber. For the test conducted on August 8-9, 2000, the calculated total time the sample spent in the dilution sampling system was 73 seconds: 2.4 seconds for the Turbulent Mixing Chamber and 70.6 seconds for the Residence Chamber.

## Sampler Control Instrumentation

Instrumentation for control and analysis of the dilution sampling system is shown in Figure 3-2. Differential pressure measurements made across the venturi and orifice meters are used to determine the dilution air flow rate, the sample gas flow rate, and the exhaust gas flow rate. Since flow equations used for determination of the flow across venturi and orifice meters correct for flowing temperature and pressure, the flowing temperature and pressure of the venturi and orifice meters must be recorded during sampling operations. Thermocouples for monitoring temperature are placed at each flow meter as well as at the inlet PM-10 cyclone, at various points on the sample inlet line, at the inlet to the Mixing Chamber U-bend, and at the outlet of the Residence Time Chamber. An electronic relative humidity probe is used to determine the relative humidity of the sample gas. The sampler is equipped with automated data logging capabilities to better monitor source testing operations and to minimize manpower requirements during sampling operations. Dilution sampler flows and temperatures are monitored and controlled automatically at setpoints established by the operator using a QSI Corporation QTERM-K65 electronic touch-screen interface. The dilution sampling system was operated by three testing staff members during the test at the wood-fired industrial boiler.

In operation, the source sample flow, the dilution air flow, and the total air flow (not including the sampling arrays) were each measured by separate flow meters and pressure transmitters. A venturi measured the source sample flow and orifices were used for the dilution and total flows. A ring compressor was used to push the dilution air through a HEPA filter, a carbon adsorber, and a final filter into the turbulent mixing chamber. The compressor motor was modulated by a variable frequency drive to match the desired dilution flow based on a setpoint entry. A separate blower (connected to a speed controller adjusted to achieve the desired sample





**Figure 3-2. Instrumentation for control and analysis of the dilution sampler.**

flow based on a setpoint entry) at the end of the sampler pulled the source sample flow through the venturi. Flow through this blower consisted of the dilution air flow plus the source sample flow not including the flow exiting through the sample collection arrays.

The main controller modulated the power used to heat the sample probe (32 in. long, one heated zone). The controller switched solid state relays on and off as needed to maintain the probe temperature entered by the operator.

### **Sample Collection Arrays**

Virtually any ambient sampling equipment (including filters, denuders, PUF cartridges, DNPH-impregnated sampling cartridges, SUMMA<sup>®</sup>-polished canisters, cyclones, particle size distribution measurement instrumentation) can be employed with the dilution sampling system. The exact number and type of sample collection arrays is uniquely configured for each testing episode.

### **Process Description/Site Operation**

With the concurrence of the EPA Work Assignment Manager, an industrial wood/bark waste-fired boiler was selected as the test site. The boiler was operated with a continuous screw-feed conveyor belt, with continuous weighing of the wood chips fed to the boiler. The test series was scheduled to minimize disruption to the normal operation of the test facility and to enable as much simultaneous data collection important to all parties as possible. ERG scheduled the sampling test at the chosen facility and obtained permission and cooperation of the site/company/management.

### ***Description of the Boiler***

The boiler was a relatively modern, field-erected, watertube, pneumatic, vibrating stoker-type unit designed and erected by Steam & Control Systems, Inc. When operating at the design heat input rate, the boiler generates 165,000 lb of steam per hour of continuous 960 psig/760 °F superheated steam.

The boiler utilized wood as the primary fuel and natural gas as start-up and backup fuel. The combustion unit was a pyrolysis system designed to gasify wood in the initial combustion zone at sub-stoichiometric air rates. The initial combustion zone is on the stoker grate. Complete combustion of the off-gases from the pyrolysis process occurs in a secondary combustion zone located above the initial combustion zone.

Emissions were controlled by a multicyclone type dust collector, followed by a multi-stage electrostatic precipitator (ESP). The multicyclone type dust collector was manufactured by Zurn Air Systems and the ESP was a model 34R-1330-37125 Electrostatic Precipitator manufactured by PPC industries.

### ***Description of the Fuel***

Boiler fuel consisted of chipped municipal and residential wood waste – i.e., branches, limbs, twigs, tree trunks, stumps, or roots – that had passed through a chipper/shredder and was delivered to the test site via dump truck for storage until use. Types of wood were unrestricted and encompassed any wood that could be grown in a yard, a municipal park, or other vegetated area. The facility utilized a large outdoor wood storage pile that was approximately 800 ft long, 800 ft wide, and 60 ft deep. Because wood chips were delivered continuously on a daily basis and distributed into the pile to ensure that the pile was stable, the age of the wood being burned at any given time varied greatly, depending on where in the pile the wood was being selected for combustion. The moisture content of this wood also varied greatly depending upon the age of

the wood chips, where the wood chips were located in the wood pile (i.e., depth) and meteorological conditions.

### ***Collection/Analysis of Fuel Samples***

While the test team was on site, two samples of wood chips that were composited from all over the wood pile were collected. These wood samples incorporated wood chips from both the top and the bottom of the wood pile, including both old and new wood chips, since a mixture of all the available wood chips is fed to the wood-fired boiler. Analysis results for the wood chips are shown in Table 3-2.

**Table 3-2. Results of the Analysis of the Wood Chips**

Parameter	As Received %	Dry Basis %
Moisture	38.90	N/A*
Volatile Matter	52.67	86.20
Fixed Carbon	7.38	12.08
Ash	1.05	1.72
Sulfur	0.01	0.02
Carbon	30.85	50.50
Hydrogen	3.55	5.81
Nitrogen	0.15	0.25
Oxygen	25.49	41.69
BTU/lb	5537	9062

\*Not applicable.

## Pre-Test Survey

A thorough survey of the test site was performed in order to determine that the test equipment would fit in the test location, to identify and gain access to the utilities needed to operate the dilution system and its ancillary equipment, to arrange for installation of sample collection ports (Figure 3-3) at the outlet of the electrostatic precipitator, and to determine the means of positioning the sampler at the desired location. A flanged sampling port was installed at the exact point in the stack where the shape became circular. ERG conducted pre-test site surveillance and site preparation to ensure readiness of the site for the start of the scheduled sampling activities. The pre-test survey considered access to utilities and personnel, legal, and safety requirements. ERG obtained limited source data such as exhaust gas flow rate and velocity, exhaust gas temperature and water vapor content, and approximate particulate matter concentration, parameters useful for estimating appropriate dilution ratios and duration of sample collection.

Arrangements were made to position the sampler on a platform at the test location (Figure 3-4). The sampling location was a flat metal deck (approximately 50 x 50 feet square) on top of the ESP system approximately 60 feet above ground level, adjacent to the 6 foot O.D. stack at the ESP outlet where the 6 inch flanged port was installed (Figure 3-4). The dilution system control module, the sampling module, and all ancillary equipment were delivered to the test site by EPA. The two modules (dilution air supply/control module and sampler module) were positioned at the sampling location using a crane supplied and operated by the facility. Electrical power (250V, single phase, 40A) was provided and installed by the facility.

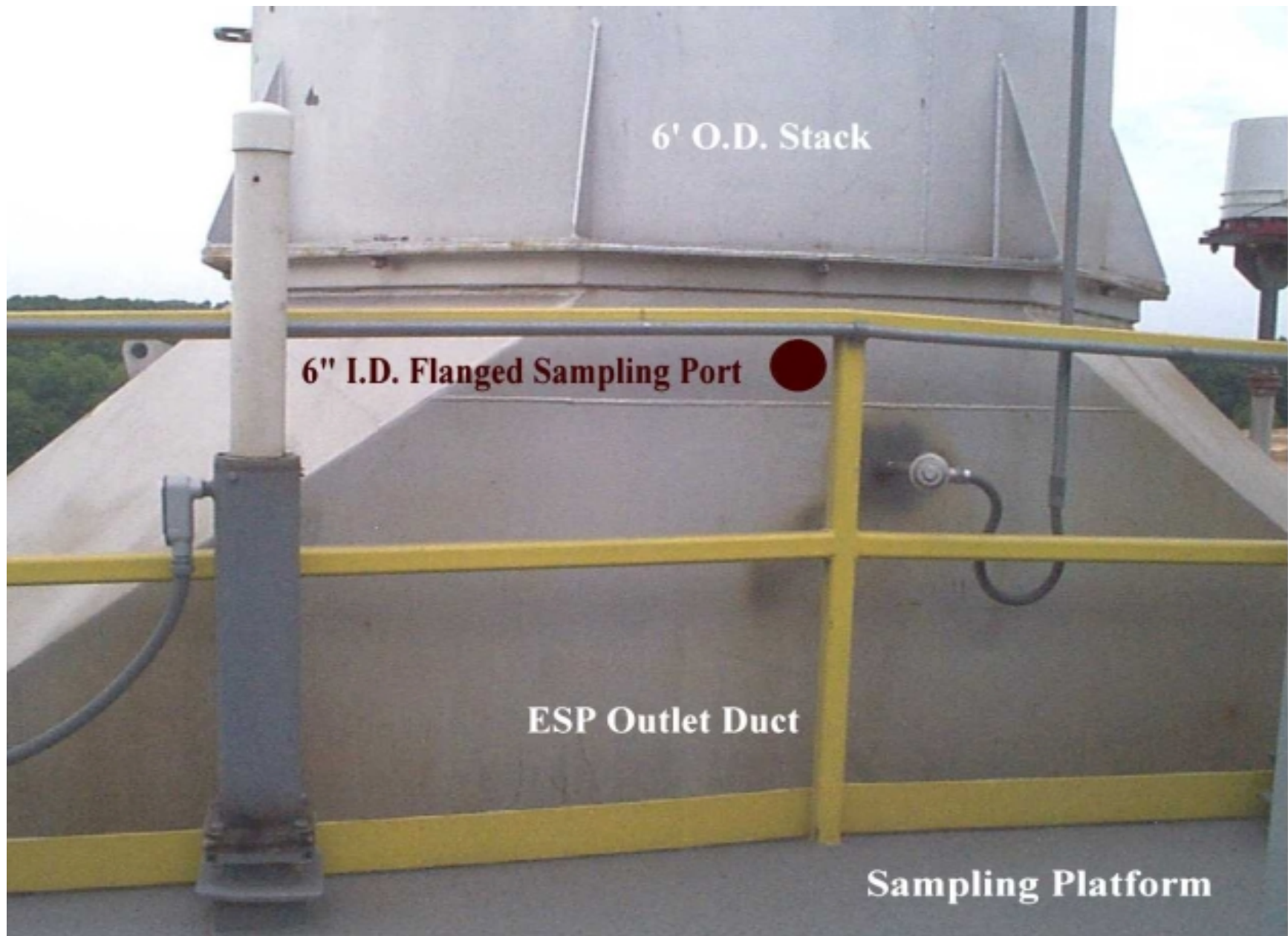
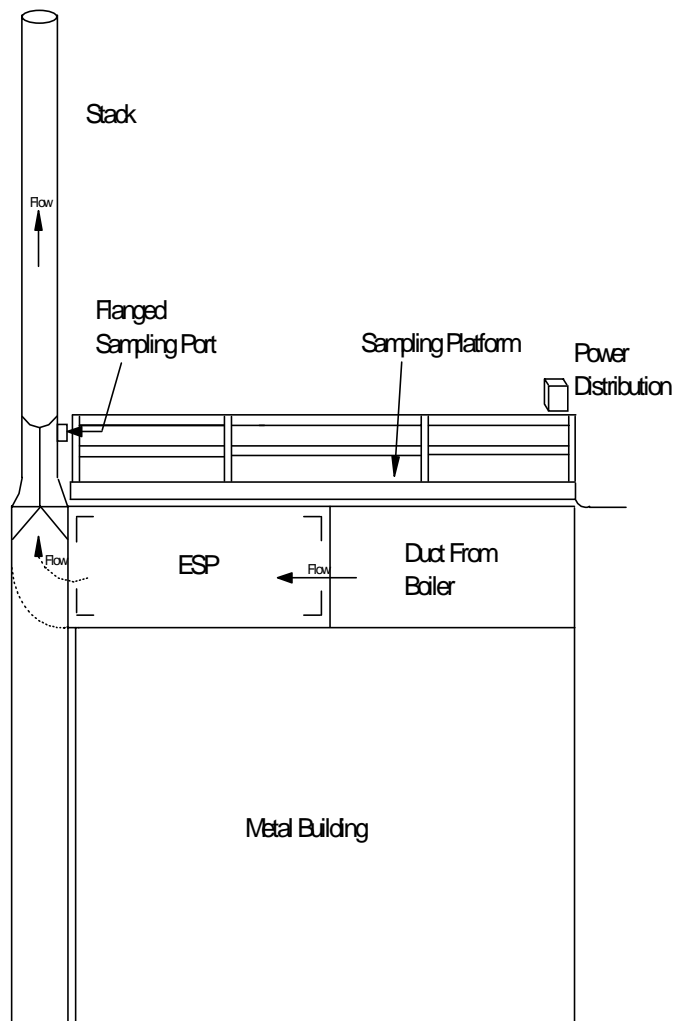


Figure 3-3. Wood-chip fired boiler test facility (SCC 10200902), sampling port.



**Figure 3-4. Schematic diagram of physical layout of process and sampling location.**

## **Section 4**

### **Experimental Procedures**

For sampling undiluted hot exhaust gas streams, the EPA/ECPB dilution sampling system (schematic diagram in Figure 3-1), sample collection arrays, sample substrates, and dilution air cleaning system were used by ERG. EPA arranged for transporting the sampler and ancillary equipment to (and from) the sampling site. To minimize introduction of contaminants, EPA pre-cleaned and pre-assembled the dilution sampler and sampling train arrays in a clean environment prior to transport to the test site. The sampler and dilution air cleaning system were assembled on separate portable aluminum frames equipped with wheels and tie-down and hoisting lugs for transport to and from the site and for positioning on a stack platform. ERG maintained the sampler and sampling trains in a contaminant-free condition prior to collection of source samples and field blanks.

A sampler blank test was run prior to transporting the sampler to the test site to ensure that the system had been cleaned properly and was leak-free. The blank test was run in the laboratory by completely assembling the sampler, including the sampling train equipment connected to the Residence Time Chamber and all instrumentation. The blank test was conducted for a time period consistent with the expected duration of the source tests (4-6 hours). Following the blank test, the sampler was shut down in reverse order from startup, and all substrates were unloaded, preserved as appropriate, and analyzed to verify the absence of contamination in the dilution sampling system.



## **Preparation for Test Setup**

Prior to deployment of the dilution sampling system at the test site and initiation of sampling with the dilution sampling system and associated sample collection arrays, EPA Methods 1-4 were used to establish key experimental parameters for the test conditions.

### ***Application of EPA Methods 1-4***

#### **Traverse Point Determination Using EPA Method 1**

EPA Method 1, “Sample and Velocity Traverses for Stationary Sources” (U.S. EPA, 1989a) was used to establish the number and location of sampling traverse points necessary for isokinetic and flow sampling. These parameters are based upon how much duct distance separates the sampling ports from the closest downstream and upstream flow disturbances.

The selected sample collection location (Figure 3-3) did not meet the minimum requirements of EPA Method 1 for length of straight run, nor for orientation of the port with respect to the plane of bends in the ductwork. However, this location was the only site with sufficient space for physical location of the sampling system. Sampling at the test site was performed at the point determined by Method 1 to represent the average velocity in the electrostatic precipitator exhaust stack (Figure 3-3).

The following stack parameters were measured:

- Inside of Far Wall to Outside of Nipple (Distance A): 74-3/8 in.
- Inside of Near Wall to Outside of Nipple (Distance B): 2-3/8 in.
- Inside Stack Dimensions: 72 in.

Traverse point locations for a circular duct (72 in. diameter) are shown in Table 4-1. A table of metric unit conversions is shown in Appendix A.

**Table 4-1. EPA Method 1—Traverse Point Location for Circular Ducts**

Traverse Point Number	Fraction of Inside Stack Dimension <sup>a</sup> %	Distance From Stack Wall (in.)	Traverse Point Location (in.)
1	2.6	1-7/8	4-1/4
2	8.2	5-7/8	8-1/4
3	14.6	10-1/2	12-7/8
4	22.6	16-1/4	18-5/8
5	34.2	24-5/8	27
6	65.8	47-3/8	49-3/4
7	77.4	55-3/4	58-1/8
8	85.4	61-1/2	63-7/8
9	91.8	66-1/8	68-1/2
10	97.4	70-1/8	72-1/2

<sup>a</sup>Inside stack diameter, 72 in. Distance from lip of flange to inside stack wall, 2-3/8 in.

The absolute pressure of the flue gas (in inches of mercury) was calculated according to the following equation:

$$PS = P_{\text{bar}} + \frac{P_g}{13.6} \quad (4-1)$$

Where:

PS = absolute gas pressure, inches of mercury  
P<sub>bar</sub> = barometric pressure, inches of mercury (29.68 in.)  
P<sub>g</sub> = gauge pressure, inches of water (static pressure) (0.31 in.)

The value 13.6 represents the specific gravity of mercury (1 inch of mercury = 13.6 inches of water). For the stack tested, the absolute gas pressure under these conditions was 29.702 inches of mercury.

## Volumetric Flow Rate Determination Using EPA Method 2

Volumetric flow rate was measured according to EPA Method 2, “Velocity - S-Type Pitot” (U.S. GPO, 1989b). A Type K thermocouple and S-type pitot tube were used to measure flue gas temperature and velocity, respectively. All of the isokinetically sampled methods that were used incorporated EPA Method 2.

### *Pitot Tube Calibration*

The EPA has specified guidelines concerning the construction and geometry of an acceptable Type-S pitot tube. If the specified design and construction guidelines are met, a pitot tube coefficient of 0.84 is used. Information pertaining to the design and construction of the Type-S pitot tube is presented in detail in Section 3.1.1 of report EPA 600/4-77-027b (von Lehmden et al., 1979). Only Type-S pitot tubes meeting the required EPA specifications were used. Pitot tubes were inspected and documented as meeting EPA specifications prior to field sampling.

### *Calculation of Average Flue Gas Velocity*

The average flue gas velocity for each traverse point is calculated using the following equation:

$$V_s = K_p * C_p * \sqrt{\frac{\Delta P_{avg} * (460 + T_s)}{P_s * M_s}} \quad (4-2)$$

Where:

$V_s$	=	average flue gas velocity, ft/sec
$K_p$	=	Pitot constant (85.49)
$C_p$	=	Pitot coefficient (dimensionless), typically 0.84 for Type S
$\Delta P_{avg}$	=	average flue gas velocity head, inches of water
460	=	zero degrees Fahrenheit expressed as degrees Rankin
$T_s$	=	flue gas temperature, degrees Fahrenheit

$P_s$	=	absolute stack pressure (barometric pressure at measurement site plus stack static pressure), in. Hg
$M_s$	=	wet molecular weight, pounds per pound-mole

The flue gas velocity calculated for each traverse point and the average velocity are shown in Table 4-2.

**Table 4-2. Average Flue Gas Velocity for Each Traverse Point (Average Flue Gas Velocity)**

<b>Traverse Point (Calculated in Table 4-1)</b>	<b>Velocity (ft/min)</b>
1	1432
2	1544
3	1547
4	1611
5	1549
6	2109
7	2296
8	2340
9	2336
10	2290
<b>Average Velocity</b>	<b>1905</b>

The point of average velocity has the closest relationship to Traverse Point #6.

### *Nozzle Size Determination*

It is desirable to sample at or near isokinetic velocities at the probe inlet nozzle. The nozzle size is based on the required sample flow rate. Prior to using an Excel® macro to perform nozzle size calculations according to the procedures of EPA Method 5 (U.S. GPO, 1989d), the

velocity in the stack (feet per minute) must be determined from the pitot traverses prior to the start of the test run. The additional input required by the macro is sampling rate (liters/minute).

### ***Measurement of O<sub>2</sub> and CO<sub>2</sub> Concentrations***

The O<sub>2</sub> and CO<sub>2</sub> concentrations were determined by use of a Fyrite bulb during the traverse.

### **Stationary Gas Distribution (as Percent Volume)**

The following values were measured by continuous emission monitors at the facility; the value for CO was supplied from compliance data collected by the facility.

Measured %O <sub>2</sub>	=	10.75%
Measured %CO <sub>2</sub>	=	10.5%
Measured %CO	=	0.03%

The percentage of nitrogen (N<sub>2</sub>) was calculated according to the following equation:

$$\% \text{ N}_2 = 100 - (\% \text{ O}_2 + \% \text{ CO}_2 + \% \text{ CO}) = 78.75\% \quad (4-3)$$

### **Dry Molecular Weight of Flue Gas**

The dry molecular weight of the flue gas (M<sub>d</sub>) was calculated according to the following equation:

$$\begin{aligned} M_d &= (\% \text{ CO}_2 * 0.44) + (\% \text{ O}_2 * 0.32) + [(\% \text{ CO} + \% \text{ N}_2) * 0.28] \\ &= 30.15 \text{ lb / lb - mole} \end{aligned} \quad (4-4)$$

Where:

M <sub>d</sub>	=	molecular weight of flue gas, dry basis (lb/lb-mole)
%CO <sub>2</sub>	=	percent CO <sub>2</sub> by volume, dry basis

%O <sub>2</sub>	=	percent O <sub>2</sub> by volume, dry basis
%CO	=	percent CO by volume, dry basis
%N <sub>2</sub>	=	percent N <sub>2</sub> by volume, dry basis
0.44	=	molecular weight of CO <sub>2</sub> , divided by 100
0.32	=	molecular weight of O <sub>2</sub> , divided by 100
0.28	=	molecular weight of N <sub>2</sub> or CO, divided by 100

### Wet Molecular Weight of Flue Gas

The wet molecular weight of the flue gas ( $M_s$ ) was calculated according to the following equation:

$$M_s = (M_d * M_{fd}) + (0.18 * \% H_2O) \quad (4-5)$$

$$= 27.77 \text{ wet lb / lb - mole}$$

Where:

$M_s$	=	wet molecular weight of flue gas, wet lb/lb-mole
$M_d$	=	molecular weight of flue gas, dry basis (lb/lb-mole)
$M_{fd}$	=	dry mole fraction of effluent gas, calculated as $[1 - \%H_2O / 100]$
0.18	=	molecular weight of H <sub>2</sub> O, divided by 100
%H <sub>2</sub> O	=	percent H <sub>2</sub> O, by volume

### ***Determination of Average Moisture Using EPA Method 4***

EPA Method 4, "Moisture Content" (U.S. GPO, 1989c), was used to determine the average moisture content of the stack gas. A gas sample was extracted from the source, moisture was removed from the sample stream, and the moisture content was determined gravimetrically. Before sampling, the initial weight of the impingers was recorded. When sampling was completed, the final weights of the impingers were recorded and the weight gain was calculated. The weight gain and the volume of gas sampled were used to calculate the average moisture content (percent) of the stack gas. The calculations were performed by computer. Method 4 was incorporated into the techniques used for all of the manual sampling methods that were used during the test.

The measurements shown in Table 4-3 were made on August 7, 2000, using Method 4 to determine moisture recovery.

**Table 4-3. Moisture Recovery for Method 4 (Measured on August 7, 2000)**

Impinger Number	Impinger Solution	Weight of Impinger Contents (g)	Impinger Tip Configuration	Impinger Weight		
				Final (g)	Initial (g)	Weight Gain (g)
1	Water	100	S6	707.3	566.0	141.3
2	Water	100	S6	653.7	598.6	55.1
3	Empty	--	MS6	499.0	488.6	10.4
4	Silica Gel	300	S6	773.2	758.8	14.4
<b>Total Weight Gain (g)</b>						<b>221.2</b>

#### Volume of Dry Gas Sampled At Standard Conditions (dscf)

The volume of dry gas sampled under standard conditions was calculated using the following equation:

$$\begin{aligned}
 V_{m(\text{std})} &= 17.64 * V_m * P_{\text{bar}} + \frac{\frac{\Delta H}{13.6}}{460 + T_m} \\
 &= 42.785 \text{ dscf}
 \end{aligned}
 \tag{4-6}$$

Where:

$V_{m(\text{std})}$	=	volume of dry gas sampled at standard conditions, dry standard cubic feet (dscf)
$V_m$	=	volume of gas metered, cubic feet, dry
$P_{\text{bar}}$	=	barometric pressure at measurement site, inches of mercury
$\Delta H$	=	Sampling rate, measured as differential pressure at the meter orifice, inches of water
$T_m$	=	dry gas meter temperature, degrees Fahrenheit

The constant 17.64 was used for conversion to standard conditions,  $(68^{\circ}\text{F} + 460^{\circ}\text{R})/29.92$  in. Hg; 460 is zero degrees Fahrenheit in degrees Rankin. Using measured values from the field data sheet, the volume of dry gas sampled at standard conditions is calculated to be 42.785 dscf.

#### Volume of Water Vapor At Standard Conditions (dscf)

The volume of water vapor under standard conditions was calculated using the following equation:

$$\begin{aligned} V_{w(\text{std})} &= 0.04707 * V_{lc} \\ &= 10.412 \text{ dscf} \end{aligned} \tag{4-7}$$

Where:

$$\begin{aligned} V_{w(\text{std})} &= \text{volume of water vapor at standard conditions, dry standard cubic feet (dscf)} \\ V_{lc} &= \text{volume of liquid catch, cubic feet} \end{aligned}$$

The constant 0.04707 is the standard cubic feet per gram (or milliliter) of water at standard conditions. Using the total weight gain for water determined using Method 4 (Table 4-3, above), the volume of water vapor at standard conditions is calculated to be 10.412 dscf.

#### Calculation of Moisture/Water Content (as % Volume)

The moisture content of the gaseous stack emissions is calculated using the following equation:

$$\begin{aligned} \% \text{ H}_2\text{O} &= 100 * \frac{V_{w(\text{std})}}{V_{w(\text{std})} + V_{m(\text{std})}} \\ &= 19.4\% \end{aligned} \tag{4-8}$$

Using values measured using EPA Method 4 and values calculated previously, the moisture content was calculated to be 19.4 percent. The value supplied by the facility was 21 percent.



## Calculation of Dry Mole Fraction of Flue Gas

The dry mole fraction of flue gas is calculated using the following equation:

$$M_{fd} = 1 - \frac{\% H_2O}{100} \quad (4-9)$$

Where:

$M_{fd}$  = dry mole fraction of effluent gas

Using the percent moisture determined above, the dry mole fraction of effluent gas is calculated as 0.806.

## Setup of the Dilution Sampling System

The sampling location was a flat metal deck on top of the ESP system approximately 60 feet above ground level, adjacent to the 6 ft O.D. stack at the ESP outlet where the 6 in. flanged port was installed (Figure 3-3). The dilution system control module, the sampling module, and all ancillary equipment were delivered to the test site by EPA. The two modules (dilution air supply/control module and sampler module) were positioned at the sampling location using a crane supplied and operated by the facility. Electrical power (250V, single phase, 40A) was provided and installed by the facility.

The location provided convenient access to the stack and sampling ports, as shown in Figure 3-3, and sufficient space for the equipment and personnel. The dilution air system module positioned at the sampling location on the flat deck is shown during operation in Figure 4-1. Because this test was conducted in the summer, the metal surface of the deck was very hot. Note that the pump was elevated above the deck surface for cooling purposes.



**Figure 4-1. Dilution system sampling module positioned at the sampling location.**

Figure 4-2 shows the sampling probe installed in the 6 in. I.D. flanged port used for sampling. The dilution air supply/control module (Figure 4-3) was located on the deck immediately adjacent to the sampling module. A TSI SMPS (Figure 4-4), with associated laptop computer, was also connected to the sampling module, together with other sampling arrays shown in the background. The dilution system sampling module with all sample collection arrays and instruments attached is shown in Figure 4-5: note the TSI SMPS in the foreground, SUMMA<sup>®</sup>-polished canister on the deck, and the various sample collection arrays (the white filter holders are readily visible) attached to the various ports of the dilution system sampling module.



**Figure 4-2. Dilution system sampling probe installed in 6 in. I.D. flanged port.**



**Figure 4-3. Dilution system control module positioned at the sampling location.**



**Figure 4-4. TSI SMPS positioned at the sampling location.**



**Figure 4-5. Dilution system with all sample collection arrays and instruments attached.**

### ***Pre-Test Leak Check***

To perform a pre-test leak check on the assembled dilution system in the field, the end of the probe was plugged with a Swagelok® fitting. Solvent-cleaned blank-off plates were inserted in place of the orifice plates at the orifice meter run flanges using gaskets on each side. A new tared quartz filter was inserted into the filter holder and the fittings were carefully sealed. A vacuum pump was attached to the residence chamber and a Magnehelic® gauge was attached to an available port. The valve between the pump and the chamber was opened and the vacuum was read as the pump was turned on. As the reading passed 27 in., the stopwatch was started and the valve between the pump and the chamber was closed. The leak rate was timed between 25 to 20 in. and again from 20 to 15 in., and the two times were averaged. Using the recorded data, the leakage rate in cubic feet/minute was calculated according to Equation 4-10.

$$\text{leakage rate} = \frac{\Delta P}{\Delta T} \times V \times CF \quad (4-10)$$

Where:

leakage rate	=	rate of leakage (ft <sup>3</sup> /min)
$\Delta P$	=	change in pressure (in. water)
$\Delta T$	=	time increment (sec)
V	=	volume of the evacuated chamber (15.3 ft <sup>3</sup> )
CF	=	unit conversion factors – 60 sec/min – 1 atm/406.8 in. water

The target time (greater than 1 minute 53 seconds, which equals 0.1 cfm) was achieved. A recorded time that was too fast or the inability to evacuate the sampler to 27 in. water would have been indicative of the presence of a leak, requiring corrective action before the sampler could be operated for the test run.



### ***Orifice Flow Check***

Critical orifice flows on the sampling pumps were checked without sample collection arrays in place using a rotameter to verify that the channels on sampling array pumps were at the specified flow rate of 16.7 L/min. Rotameters were calibrated with a NIST-traceable electronic bubble flow meter and the readings were converted to flow (L/min) using a spreadsheet.

### ***Determination of Test Duration***

A pre-test was performed prior to the initiation of source testing to establish the length of the test runs. The pre-test was used to assess whether there were any problems with the source testing operations and to obtain an estimate of the substrate loadings during the actual source tests to avoid overloading the substrates. To perform the pre-test, two arrays consisting of two sets of paired filters, one dedicated to determination of collected mass and the other dedicated to the determination of elemental and organic carbon, were attached to the Residence Time Chamber. The dilution sampling system was operated for a period of two hours, and the resulting samples were transported to the EPA laboratories in Research Triangle Park that evening for analysis. The results of the analysis (the loading on the test filters) demonstrated that the maximum achievable integration time should be used for the test runs. The equipment used to collect the integrated canister samples dictated a maximum integration time of six hours for the test runs since the canisters were used to collect an integrated sample over the duration of the test run.

### ***Canister/Veriflow Blanks***

Prior to deployment in the field, SUMMA<sup>®</sup>-polished canisters and Veriflow<sup>®</sup> canister filling units were cleaned and blank analysis was performed in the laboratory. All units met the cleanliness criterion of < 10 parts per billion carbon (ppbC, Table 4-4).

**Table 4-4. Blank Values for Veriflows® and Canisters**

Unit	Blank Value, ppbC
<b>Veriflows®</b>	
Unit #418 (Source), Field Test 1	0.4
Unit #315 (Dilution Air), Field Test 2	0.2
<b>Canisters</b>	
3942	0.3
4040	0.2
3953	0.3
1478	0.9
4043	0.5
1408	0.3
1473	0.3
1425	0.6
4031	1.1

***Determination of Flow Rates***

A Visual Basic® macro was written to process raw data files of flow rate information and convert this information to actual flow based on temperature, pressure, and calibration data. For venturi flows, the macro converted differential pressure into a reported flow rate. The square root of the differential pressure was then multiplied by a previously determined calibration factor based on the flowing temperature, and the resulting value was converted to standard liters per minute (sLpm) using ideal gas law relationships (1 atm, 70 °F).

Calibration data for the venturi were generated by placing a dry gas meter at the inlet to the sample probe. The flows reported by the data acquisition system were corrected to actual conditions (aLpm) and compared to those produced by the dry gas meter corrected to the venturi conditions. An Excel® macro automatically selected a correct calibration value to be applied based on the flowing temperature.

Since the actual venturi flow was dependent upon the operating conditions, the setpoint value displayed and entered on the viewing screens needed to be adjusted to achieve the desired flow. Information to be entered included desired flow, flow temperature, flow pressure, and barometric pressure; the Excel<sup>®</sup> macro automatically selected the correct value to be applied based on the flow temperature.

Flow information collected during the pre-test (August 7, 2000) is summarized in Table 4-5. The flows for the blower, dilution, and venturi air are shown graphically in Figures 4-6, 4-7, and 4-8, respectively.

### Sample Collection Arrays

Prior to actual testing (Test Run #1 on August 8, 2000, and Test Run #2 on August 9, 2000), sample collection arrays were attached to various ports on the dilution sampler, as shown in Figure 4-9. Up to ten sampling ports were available attached to either the Dilution Chamber or the Residence Chamber (available sampling ports are shown in Figure 3-1). The following arrays were used for Test #1 and Test #2:

- **Port #D1 (Dilution Chamber)**  
The sample collection array used on Port #D1 (Dilution Chamber) included a PM-2.5 cyclone branching off to two sample collection systems: one a quartz filter (QF) followed by a polyurethane foam (PUF) sampling module, the second a Teflon<sup>®</sup> filter (TF) followed by a KOH-impregnated quartz filter (KOH-QF) for collection of volatile organic acids. This array collected semivolatile organic compounds, particles, and particle phase organic compounds, as well as any semivolatile organic compounds that may have been volatilized from the filters.



**Table 4-5. Run Time Flow Summary Information: Pre-Test, August 7, 2000**

Start Time	6:38:38 PM
End Time	8:28:19 PM
Run Time	109.68 minutes
Barometric Pressure	29.63 in. Hg

Parameter	Average
Venturi Flow	30.08 aLpm <sup>c</sup> 17.26 sLpm <sup>d</sup>
PT-101 <sup>a</sup>	-1.09 in. WC <sup>e</sup>
TE-104 <sup>b</sup>	233.55 °C
Dilution Flow	891.10 aLpm 828.58 sLpm
PT-102	-1.34 in. WC
TE-108	36.58 °C
Blower Flow	967.85 aLpm 874.56 sLpm
PT-103	-14.92 in. WC
TE-105	39.07 °C
Dilution Ratio	49.24
TE-101	224.97 °C
TE-102	227.62 °C

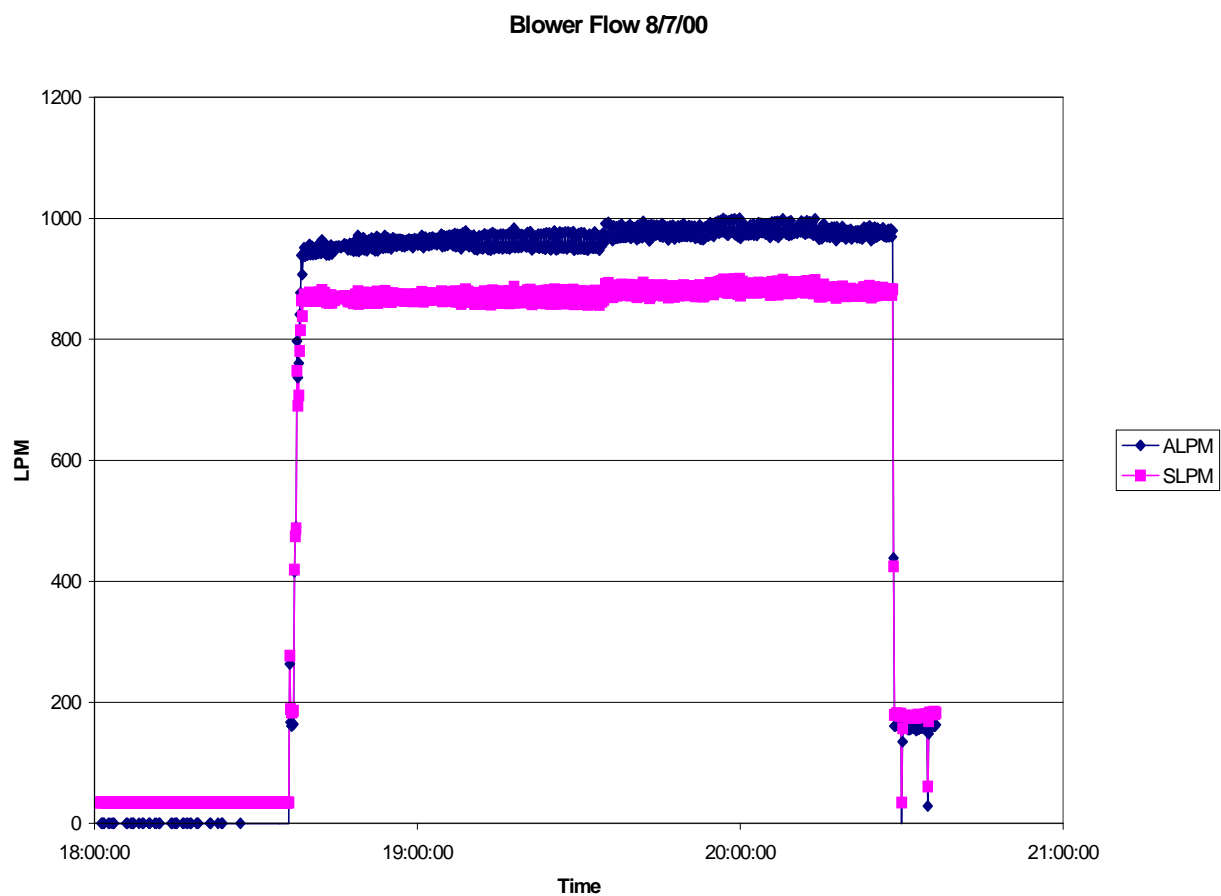
<sup>a</sup>PT = pressure transducer

<sup>b</sup>TE = thermocouple

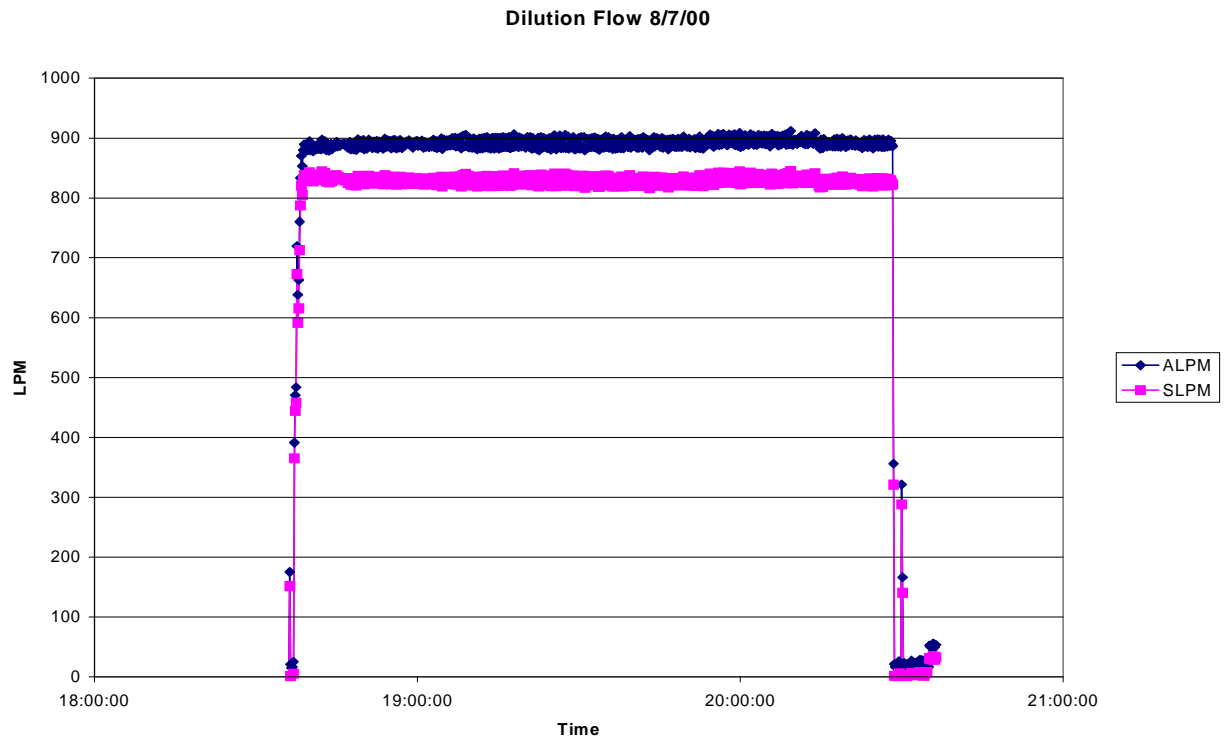
<sup>c</sup>aLpm = actual liters per minute

<sup>d</sup>sLpm = standard liters per minute

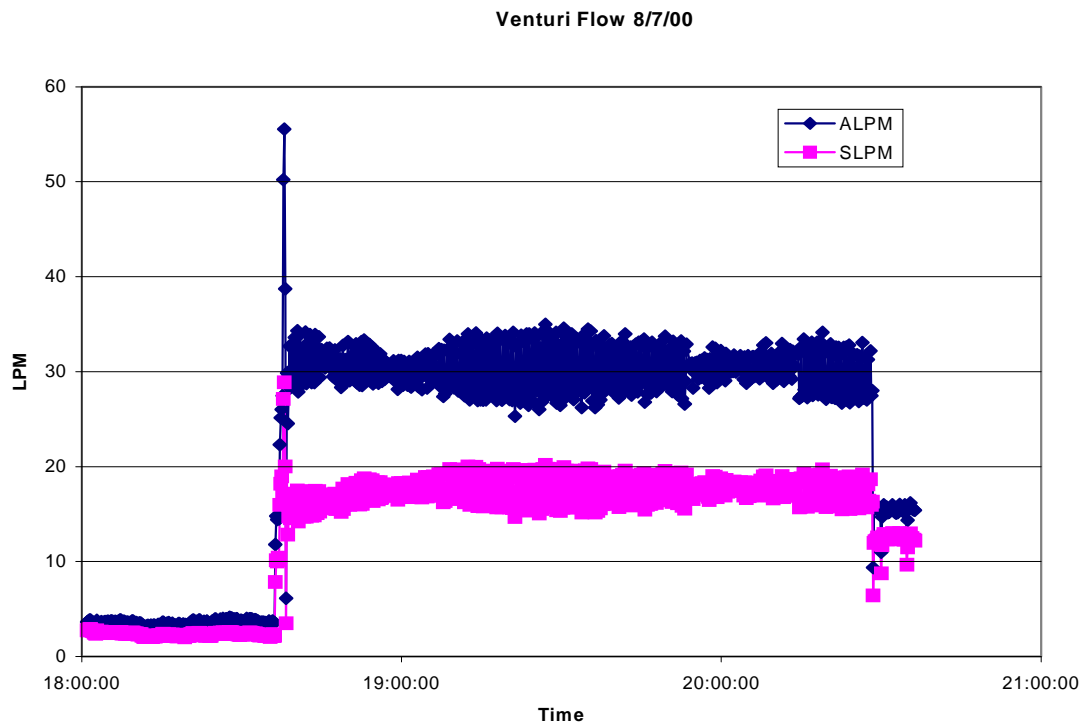
<sup>e</sup>WC = water column



**Figure 4-6. Blower flow, pre-test, August 7, 2000.**



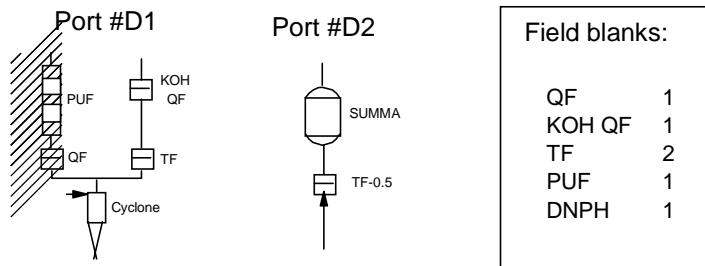
**Figure 4-7. Dilution flow, pre-test, August 7, 2000.**



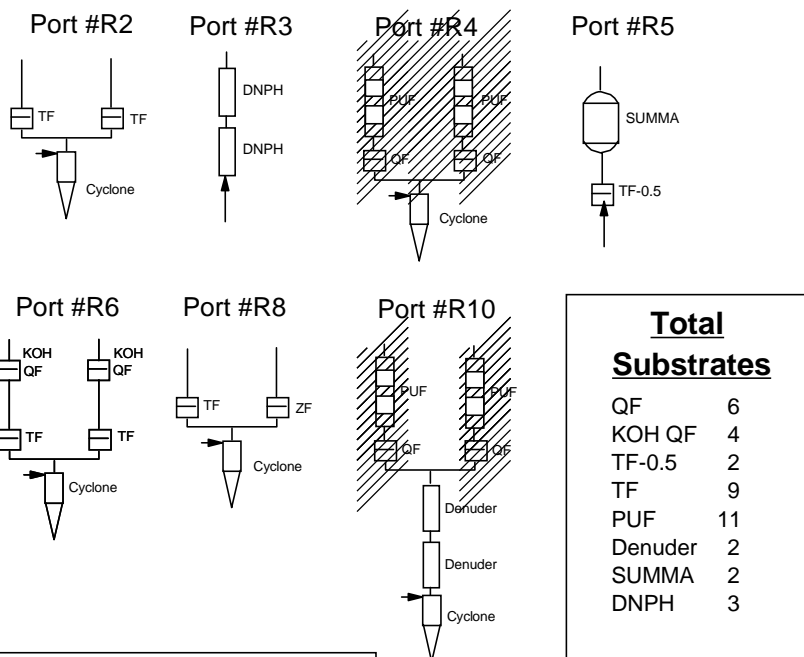
**Figure 4-8. Venturi flow, pre-test, August 7, 2000.**

Test: 8/8/00

#### Dilution chamber



#### Residence chamber



#### Legend

QF	=	Quartz Filter
KOH QF	=	KOH Quartz Filter
TF-0.5	=	Teflon® Filter - 0.5
TF	=	Teflon® Filter
PUF	=	Polyurethane Foam Sampling Module
Denuder	=	Denuder
SUMMA	=	SUMMA® Canister
DNPH	=	2,4-Dinitrophenylhydrazine -impregnated silica gel cartridge

Figure 4-9. Schematic diagram of sample collection arrays used in field test (August 8-9, 2000).

- **Port #D2 (Dilution Chamber)**  
The sample collection array used on Port #D2 (Dilution Chamber) included a Teflon<sup>®</sup> filter followed by a cleaned and blanked SUMMA<sup>®</sup>-polished stainless steel canister for the collection of volatile organic compounds. The canister collected whole air samples for analysis of air toxics and Speciated Nonmethane Organic Compounds, with a Teflon<sup>®</sup> filter to protect the canister from particulate contamination.
- **Port #R2 (Residence Chamber)**  
The sample collection array used on Port #R2 (Residence Chamber) included a PM-2.5 cyclone leading into two Teflon<sup>®</sup> filters in parallel to collect fine particulate matter for determination of PM mass and elemental composition.
- **Port #R3 (Residence Chamber)**  
The sample collection array used on Port #R3 (Residence Chamber) consisted of two DNPH-impregnated silica gel tubes in series for collection of carbonyl compounds.
- **Port #R4 (Residence Chamber)**  
The sample collection array used on Port #R4 (Residence Chamber) consisted of a PM-2.5 cyclone leading into two parallel assemblies consisting of quartz filters followed by PUF plugs. This array collected semivolatile organic compounds, particles, and particle phase organic compounds, as well as any semivolatile organic compounds that may have been volatilized from the filters.
- **Port #R5 (Residence Chamber)**  
The sample collection array used on Port #R5 (Residence Chamber) consisted of a Teflon<sup>®</sup> filter followed by a cleaned and blanked SUMMA<sup>®</sup>-polished canister for collection of Volatile Organic Compounds. The canister collected integrated whole air samples for analysis of air toxics and Speciated Nonmethane Organic Compounds, with a Teflon<sup>®</sup> filter to protect the canister from particulate contamination.
- **Port #R6 (Residence Chamber)**  
The sample collection array used on Port #R6 (Residence Chamber) included a PM-2.5 cyclone leading into two parallel assemblies consisting of Teflon<sup>®</sup> filters followed by KOH-impregnated quartz filters for collection of fine particulate material and volatile organic acids, respectively.
- **Port #R7 (Residence Chamber)**  
The sample collection assembly used on Port #R7 (Residence Chamber) consisted of an aerodynamic particle-sizing spectrometer to separate particles by size for high-resolution measurements of particle size distribution. The instrumentation utilized was the TSI Model 3025A (Ultra Fine Condensation Particle Counter)

coupled with the TSI Model 3080 (Electrostatic Classifier), collectively described as the Scanning Mobility Particle Sizer (SMPS).

- **Port #R8 (Residence Chamber)**  
The sample collection array used on Port #R8 (Residence Chamber) consisted of a cyclone leading into two parallel Teflon<sup>®</sup> filters (supplied by a second vendor) for collection of fine particulate matter for determination of major inorganic ions and PM mass.
- **Port #R10 (Residence Chamber)**  
The sample collection array used on Port #R10 (Residence Chamber) included a cyclone leading into a set of two 200 mm long XAD-4<sup>®</sup>-coated denuders in series followed by two parallel quartz filters both leading into PUF sampling modules. These denuder-equipped arrays provide an alternative method for distinguishing gas- and particle-phase semivolatile organic compounds.

## Preparation of the Particle Size Distribution Analyzer

The Scanning Mobility Particle Sizer (consisting of the TSI Model 3025A Ultra Fine Condensation Particle Counter combined with the TSI Model 3080 Electrostatic Classifier) was used to make particle size distribution measurements in the range of 10-400 nanometers (nm) midpoint diameter. The Electrostatic Classifier separates particles by size for high-resolution measurements. Monodisperse aerosol exiting the Electrostatic Classifier passes to the Condensation Particle Counter, which measures particle number concentrations. By scanning quickly through the desired size range, the Scanning Mobility Particle Sizer measures the size distribution of the aerosol precisely, providing concentration and size-resolution measurements with a high degree of accuracy.

In operation, a polydisperse submicrometer aerosol passes through a radioactive bipolar charger, establishing a bipolar equilibrium charge level on the particles. Nearly all particles in the range scanned receive a single positive, single negative, or zero charge. The particles then enter the differential mobility analyzer and are separated according to their electrical mobility, which is inversely related to particle size.

The pre-calibrated instrument was transported to the field and placed in the vicinity of the sampling array on a sturdy table. Thirty minutes prior to the start of the test run, the SMPS was turned on to warm up and equilibrate. The computer was turned on, and the sample acquisition program was initiated. On the SMPS, the sample flow and the sheath flow were manually adjusted to the manufacturer's specifications (sample flow equal to 0.6 Lpm; total flow 6 Lpm).

The Teflon<sup>®</sup> and quartz filters used in the dilution sampling system had a pore size of 2  $\mu\text{m}$ . This filter pore size was selected for the dilution sampling system because the system pressure drop across the filter was too great with a filter pore size of 1  $\mu\text{m}$ . The SMPS was set to monitor the range of 10-400 nm midpoint diameter to provide an indication of the particle size distribution in the range below 2  $\mu\text{m}$ , as well as the concentration distribution of the particles within this size range. The data system was initially set up to collect data for particles ranging from 10 to 400 nm in size; particles larger in diameter than 400 nm were not collected. The particles were collected over multiple three-minute periods for the duration of the test with a filter in the inlet line to establish the absence of background contamination.

Shortly before the test run, the data system was programmed to collect particulate data that encompassed the expected duration of the test run. The instrument completed an upward/downward scan every three minutes, producing particle size and concentration data for the selected scan range. The particle size analyzer was the last piece of equipment connected to the Residence Chamber. When the test was started, the filter was removed from the inlet line of the particle sizer, the inlet line was attached to the port, and "Start Run" was initiated on the data system. Data were continually saved on the computer hard drive and a real-time display on the computer screen showed the particle distribution. Graphical presentations of the data were prepared off-line.

## Operation of the Dilution Sampling System with Sample Collection Arrays

After completion of the pre-test run to establish experimental parameters for the test, the dilution sampling system was prepared for a full test run. Sampling probe temperature setpoints

were set equal to or slightly above the measured stack temperature. The system was equilibrated at temperature. Sampling arrays were loaded with appropriate media and flow/leak checks were performed with each array to ensure that the entire system would be leak-free in operation. Sampler flows were set just before initiation of the test to prevent heat loss from the heated probe. The blower and the ring compressor were started to achieve a slightly positive pressure, then the blower flow was adjusted to cause the stack gas to flow into the dilution sampling system after the probe was inserted in the stack. Sample collection array pumps were started and valves for the SUMMA<sup>®</sup> canisters were opened to initiate canister air sample collection. The sampling process was carefully monitored by the sampling team based on the pressure change in the canister to ensure that filters were not overloaded in the course of sampling. Start time and other pertinent data were recorded. At the end of the predetermined sampling interval, the sampling process was stopped by stopping the pumps for the sample collection arrays and closing the valves on the SUMMA<sup>®</sup>-canisters. The probe was withdrawn from the stack, the blower and ring compressor were turned off, and heaters were turned off and allowed to cool. Each sampling array was leak-checked at the end of the sampling period and ending flow rates were documented. Experimental parameters for Test #1 and Test #2 are shown in Tables 4-6 and 4-7; blower flow, dilution flow, and venturi flow for Tests #1 and #2 are shown graphically in Figures 4-10 through 4-15.

#### Dilution System Sample Collection Arrays: Train Recovery

When the sampling run was completed, the pumps on the dilution system were turned off and recovery of the dilution sampling system consisted of removing the sample collection arrays and turning off the particle size analyzer. The SMPS was then connected to a small HEPA-filter unit and pulled ambient air through the filter and analyzer so that the unit could collect post-sampling blanks.



**Table 4-6. Run Time Summary Information, Test Run #1 (August 8, 2000)**

<b>Test Run #1 (August 8, 2000)</b>			
Start Time	12:58:27 PM		
End Time	5:16:21 PM		
Run Time	257.90 min		
Barometric Pressure	29.65 in. Hg		
Nozzle Size	#8 (227 °C, 1905 ft/min)		
Canister Flow	13.9 cm <sup>3</sup> /min		
<b>Parameter</b>	<b>Average</b>		
<b>Venturi Flow</b>	30.47 aLpm		
	17.19 sLpm		
PT-101	-2.96 in. WC		
TE-104	239.86 °C		
<b>Dilution Flow</b>	900.35 aLpm		
	822.40 sLpm		
PT-102	-3.06 in. WC		
TE-108	40.95 °C		
<b>Blower Flow</b>	909.56 aLpm		
	809.53 sLpm		
PT-103	-16.11 in. WC		
TE-105	44.15 °C		
<b>Dilution Ratio</b>	48.90		
TE-101	240.25 °C		
TE-102	238.98 °C		
TE-103	NA		
<b>Sample Flow Rates</b>			
<b>Actual Flow aLpm</b>	<b>Corrected Flow sLpm</b>	<b>Notes</b>	<b>Average Flow sLpm</b>
16.09	17.20	PM2.5 Sample, Dilution Air: Start	17.28
16.24	17.36	PM2.5 Sample, Dilution Air: End	
16.53	17.67	PM2.5 Sample, Residence Chamber (Port 10): Start	17.59
16.39	17.51	PM2.5 Sample, Residence Chamber (Port 10): End	

(Continued)

**Table 4-6. (Continued)**

<b>Sample Flow Rates</b>			
<b>Actual Flow aLpm</b>	<b>Corrected Flow sLpm</b>	<b>Notes</b>	<b>Average Flow sLpm</b>
16.97	18.14	PM2.5 Sample, Residence Chamber (Port 8): Start	18.06
16.82	17.98	PM2.5 Sample, Residence Chamber (Port 8): End	
16.53	17.67	PM2.5 Sample, Residence Chamber (Port 6): Start	17.74
16.68	17.82	PM2.5 Sample, Residence Chamber (Port 6): End	
16.53	17.67	PM2.5 Sample, Residence Chamber (Port 4): Start	17.67
16.53	17.67	PM2.5 Sample, Residence Chamber (Port 4): End	
16.82	17.98	PM2.5 Sample, Residence Chamber (Port 2): Start	17.74
16.39	17.51	PM2.5 Sample, Residence Chamber (Port 2): End	
0.98	1.05	DNPH Sample, Residence Chamber (Port 3): Start	1.04
0.96	1.03	DNPH Sample, Residence Chamber (Port 3):End	
<b>Canisters</b>			
	<b>Start Pressure</b>	<b>End Pressure</b>	
#1473, Dilution	29.5 in. Hg	9.0 in. Hg	
#4043, Source	29.0 in. Hg	7.0 in. Hg	
#4031, Blank	29.5 in. Hg	29.5 in. Hg	

NA = Not applicable; channel not connected.

PT = pressure transducer

TE = thermocouple

aLpm = actual liters per minute

sLpm = standard liters per minute

WC = water column

**Table 4-7. Run Time Summary Information, Test Run #2 (August 9, 2000)**

Test Run #2 (August 9, 2000)			
Start Time	9:07:38 AM		
End Time	3:07:17 PM		
Run Time	359.65 min		
Barometric Pressure	29.62 in. Hg		
Nozzle Size	#8 (227 °C, 1905 ft/min)		
Canister Flow	13.9 cm³/min		
Parameter	Average		
Venturi Flow	30.05 aLpm		
	17.06 sLpm		
PT-101	-2.84 in. WC		
TE-104	236.32 °C		
Dilution Flow	898.27 aLpm		
	823.46 sLpm		
PT-102	-2.89 in. WC		
TE-108	39.66 °C		
Blower Flow	898.15 aLpm		
	804.22 sLpm		
PT-103	-15.58 in. WC		
TE-105	42.44 °C		
Dilution Ratio	49.33		
TE-101	225.94 °C		
TE-102	236.83 °C		
TE-103	NA		
Sample Flow Rates			
Actual Flow aLpm	Corrected Flow sLpm	Notes	Average Flow sLpm
16.84	17.96	PM2.5 Sample, Dilution Air: Start	17.88
16.69	17.81	PM2.5 Sample, Dilution Air: End	
16.55	17.65	PM2.5 Sample, Residence Chamber (Port 10): Start	17.65
16.55	17.65	PM2.5 Sample, Residence Chamber (Port 10): End	

(Continued)

**Table 4-7. (Continued)**

<b>Sample Flow Rates</b>			
<b>Actual Flow aLpm</b>	<b>Corrected Flow sLpm</b>	<b>Notes</b>	<b>Average Flow sLpm</b>
16.69	17.81	PM2.5 Sample, Residence Chamber (Port 8): Start	17.88
16.84	17.96	PM2.5 Sample, Residence Chamber (Port 8): End	
16.55	17.65	PM2.5 Sample, Residence Chamber (Port 6): Start	17.65
16.55	17.65	PM2.5 Sample, Residence Chamber (Port 6): End	
16.55	17.65	PM2.5 Sample, Residence Chamber (Port 4): Start	17.73
16.69	17.81	PM2.5 Sample, Residence Chamber (Port 4): End	
16.84	17.96	PM2.5 Sample, Residence Chamber (Port 2): Start	17.96
16.84	17.96	PM2.5 Sample, Residence Chamber (Port 2): End	
0.96	1.02	DNPH Sample, Residence Chamber (Port 3): Start	1.02
0.96	1.02	DNPH Sample, Residence Chamber (Port 3):End	
<b>Canisters</b>			
	<b>Start Pressure</b>	<b>End Pressure</b>	
#1478, Dilution	29 in. Hg	4.0 in. Hg	
#4040, Source	30 in. Hg	2.5 in. Hg	
#3953, Blank	29 in. Hg	29 in. Hg	

NA = Not applicable; channel not connected.

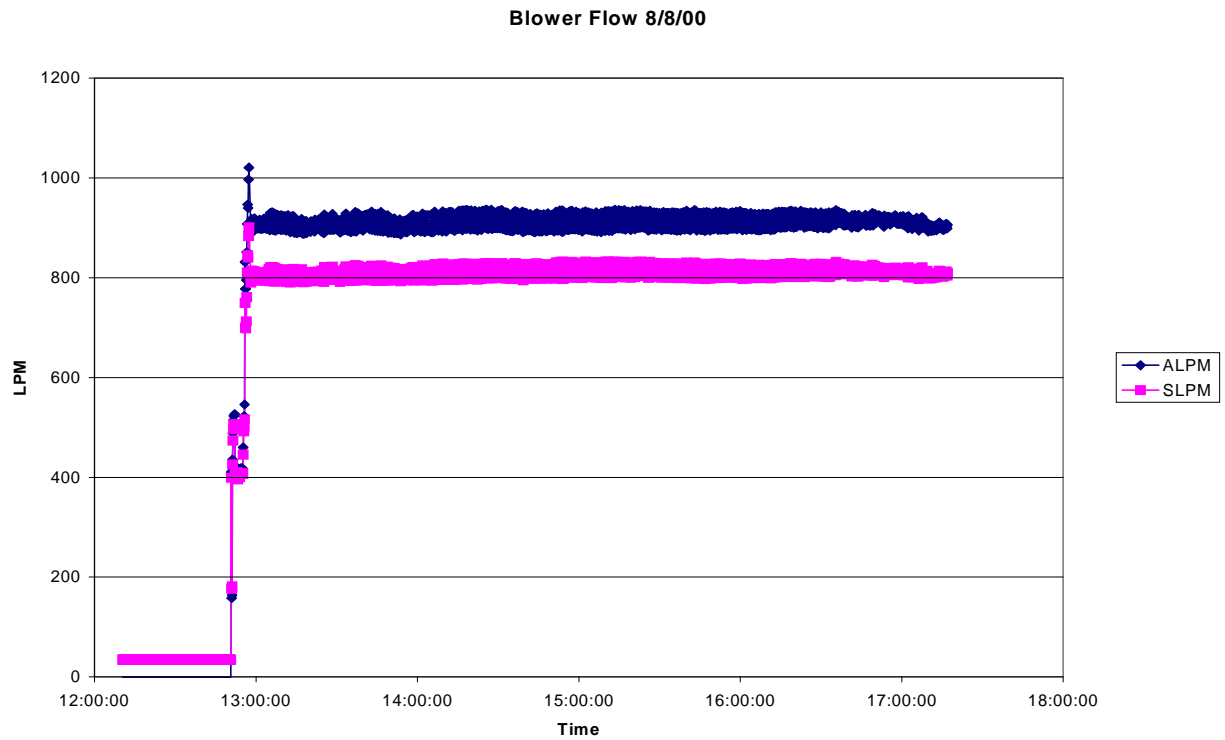
PT = pressure transducer

TE = thermocouple

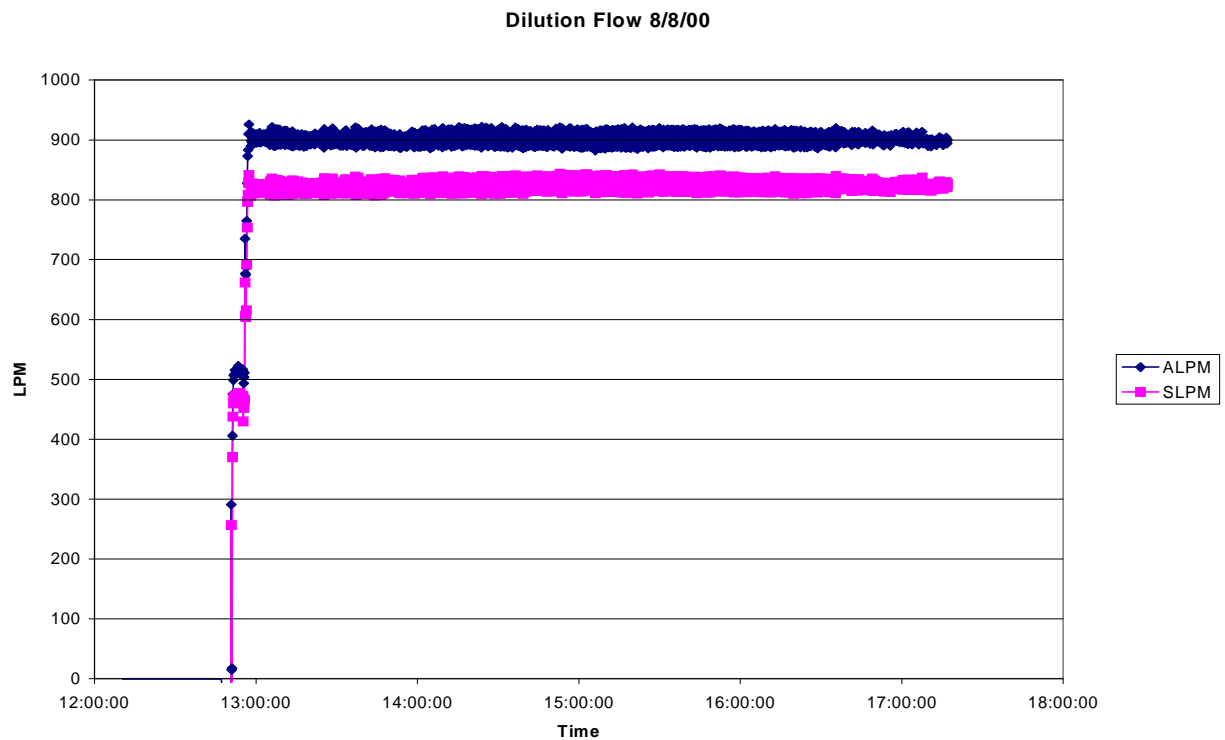
aLpm = actual liters per minute

sLpm = standard liters per minute

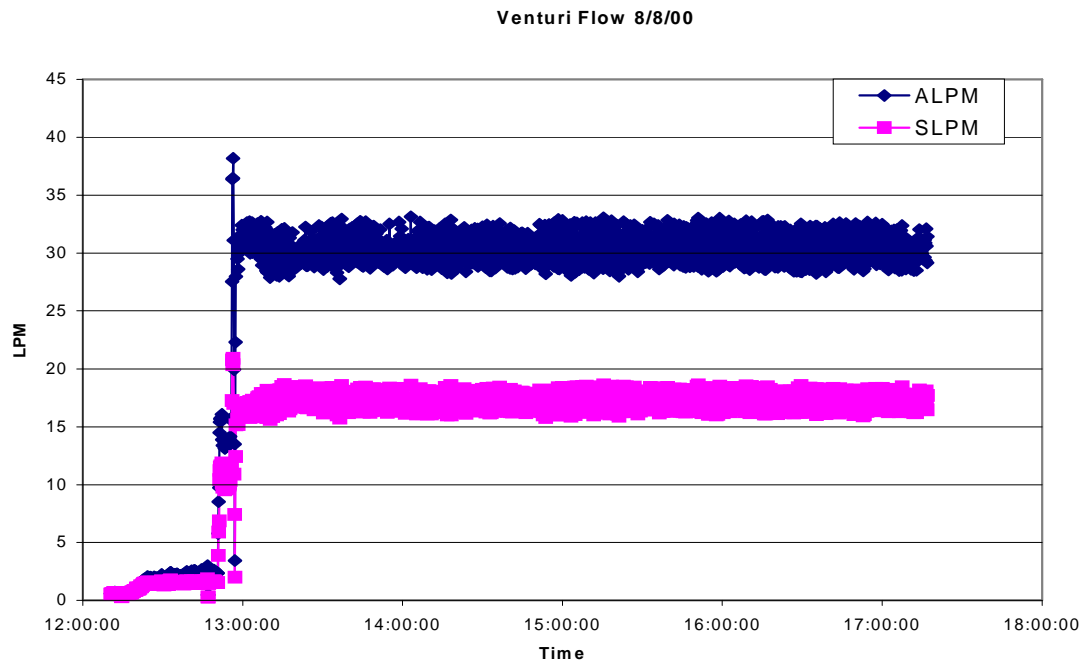
WC = water column



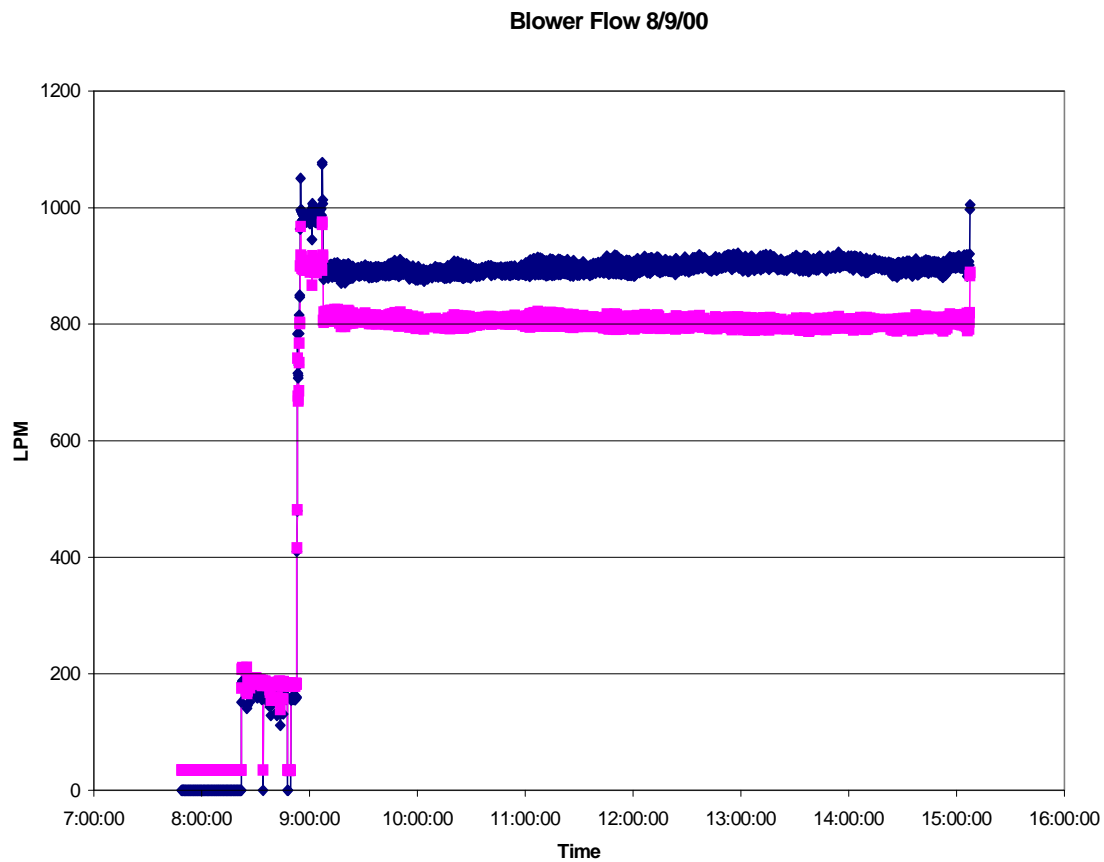
**Figure 4-10. Blower flow, Test 1—Day 1, August 8, 2000.**



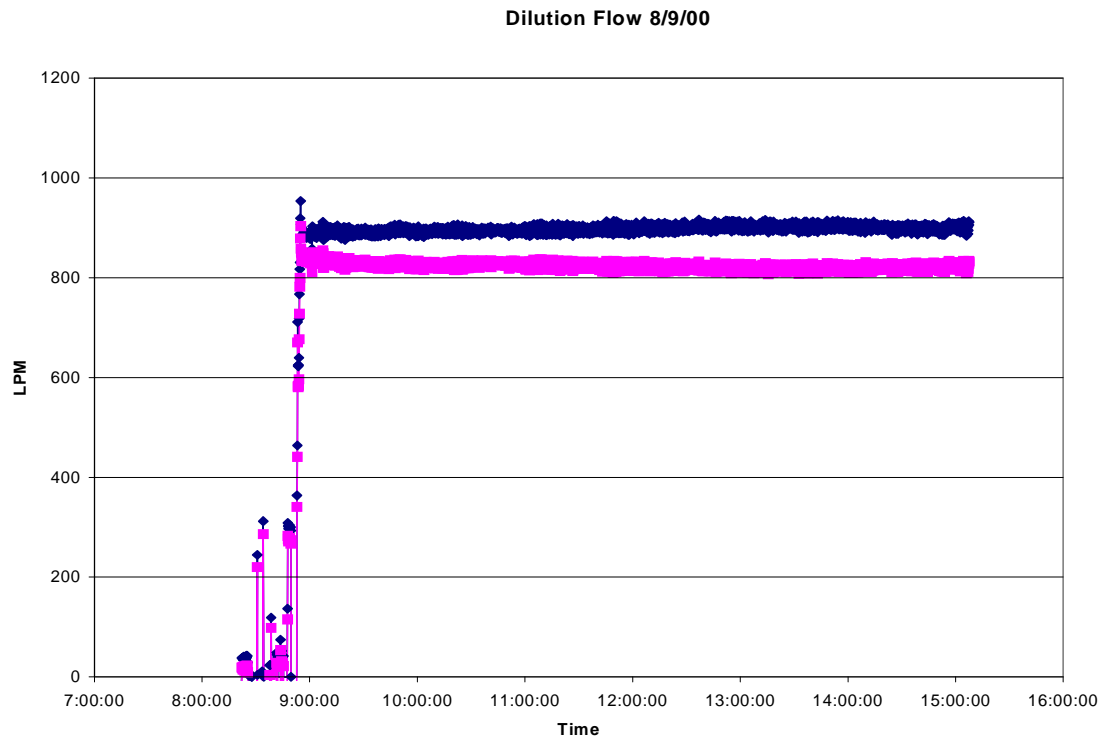
**Figure 4-11. Dilution flow, Test 1—Day 1, August 8, 2000.**



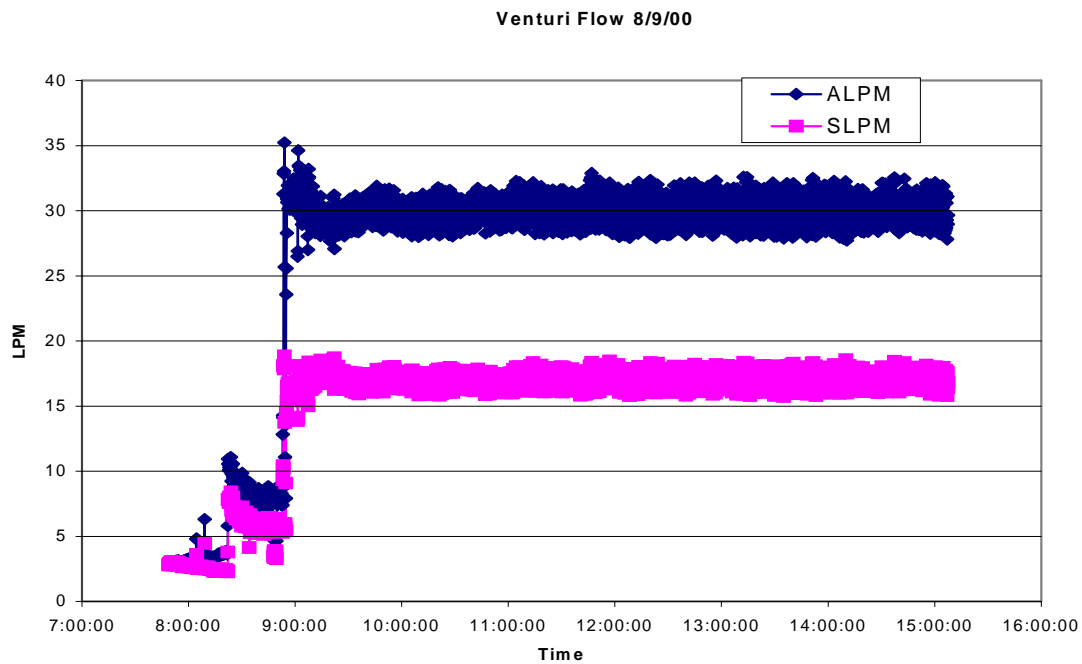
**Figure 4-12. Venturi flow, Test 1—Day 1, August 8, 2000.**



**Figure 4-13. Blower flow, Test 2—Day 2, August 9, 2000.**



**Figure 4-14. Dilution flow, Test 2—Day 2, August 9, 2000.**



**Figure 4-15. Venturi flow, Test 2—Day 2, August 9, 2000.**

The sample collection arrays were removed sequentially at the cyclone connection. Each individual collection array was removed and the ends of the assembly were covered with aluminum foil. As each sample collection array was removed from the sampling system, the sampling aperture was covered to avoid introduction of any contaminants into the dilution sampler. The ends of the sample collection array were capped and the array placed upright in a secure container for transport to the sample recovery area.

In the sample recovery area, the sample collection arrays were disassembled into the following components:

- Polyurethane foam (PUF) modules were disassembled from the sample collection array as a module. Both ends of the PUF sampling module were capped, the module placed in a sealable plastic bag, the bag appropriately labeled, and chain of custody documentation initiated.
- Filters were positioned in specific filter holder assemblies as part of several of the sample collection arrays. In the sample recovery area, the filter holder assemblies were disassembled, and the filter was removed with Teflon<sup>®</sup> tipped tweezers and placed in a pre-numbered custom filter container with a locking lid. The appropriate label was affixed to the filter container and chain of custody documentation initiated. The filter holder assembly was re-assembled without the filter, placed in a plastic bag, and labeled.
- Denuders were disassembled, the ends of the sorbent tube closed with Teflon<sup>®</sup> caps and sealed with Teflon<sup>®</sup> tape, the sealed denuder tubes placed in a plastic bag, labeled, and chain of custody documentation initiated.
- Carbonyl sampling tube assemblies (two carbonyl sampling tubes in series) were disassembled. The ends of the individual tubes were sealed with plastic caps and the sealed tubes placed in an aluminum foil packet, labeled to preserve the front/back order from the sample collection array, placed in a plastic bag, labeled, and chain of custody documentation initiated.
- Canister sampling was terminated by closing the valve on the canister at the end of the sampling period. The canister with closed valve was disconnected from the dilution system and capped; chain of custody documentation was generated.

Denuders, PUF modules, and filters were all bagged and stored over ice.



At a later time, extraction on-site was performed for the denuders. The denuders were rinsed with a mixture of methylene chloride: acetone: hexane in a volume ratio of 2:3:5. The solvent mixture was added to the denuder and the denuder tube was capped and shaken (4 times). An internal standard was added to the first extraction. The rinses were combined in a pre-cleaned glass jar for paired denuders, the jar was labeled, sealed with Teflon<sup>®</sup> tape, chain of custody documentation was initiated for the extract, and the jar was stored over ice. After extraction, the denuders and caps were dried using high purity nitrogen and capped until ready for re-use.

Canisters and carbonyl tubes were transported to the ERG laboratory for analysis and the filters, PUF modules, and denuder extracts were transported to the EPA laboratory for analysis.

## **Laboratory Experimental Methodology**

Components of the sample collection arrays, filters, DNPH-impregnated silica gel tubes used to sample carbonyl compounds, and canisters used to sample volatile organic compounds were returned for analysis to EPA and ERG laboratories, respectively (see Table 3-1 for responsible laboratory). The analyses described in the following sections were performed with the analytical methodology used by the respective laboratories summarized in Table 3-1.

### ***PM-2.5 Mass***

Teflon<sup>®</sup> membrane (Gelman Teflo<sup>®</sup>) filters of 2 µm pore diameter were used to collect fine PM samples for mass determinations. Filters before and after sample collection were maintained at 20-23 °C and a relative humidity of 30-40% for a minimum of 24 hours prior to weighing on a micro-balance. Sample mass was determined by gravimetric analysis before and after sample collection.

## ***Elemental Analysis***

Individual elements above atomic number 9 (fluorine) were measured using a Philips Model 2404, wavelength-dispersive, X-ray fluorescence (XRF) spectrometer running the UniQuant™ program. This program gives qualitative and quantitative information on the elements present on a Teflon® membrane filter. The filter to be analyzed was covered with a 0.4 µm thick Prolene® film which was attached using glue. The glue was only on the outer rim of the filter and did not interfere with the analysis. Only elements which gave amounts greater than 1 standard error above the detection limit were reported.

## ***Water-Soluble Inorganic Ions***

Teflon® filter samples were analyzed for major inorganic anions and cations using a Dionex DX-120 ion chromatograph equipped with a 25 µL sample loop and a conductivity detector. Major ions determined were chloride, nitrate, sulfate, calcium, magnesium, potassium, and ammonium. Prior to extraction the filters were wetted with 350-500 µL of ethanol. Two sequential extractions with High Performance Liquid Chromatography (HPLC)-grade water were performed using mild sonication of the filters followed by filtration of the extracts. The two extracts were combined for analysis.

Anions were separated using an Ion Pac AS14 (4 x 250 mm) column with an alkyl quaternary ammonium stationary phase and a carbonate-bicarbonate mobile phase. Cations were separated using an Ion Pac CS12 (4 x 250 mm) column with an 8 µm poly(ethylvinylbenzene-divinylbenzene) macroporous substrate resin functionalized with a relatively weak carboxylic acid stationary phase and a sulfuric acid mobile phase. Ion concentrations were determined from four-point calibration curves using an external standard method. All samples were extracted and analyzed in duplicate or triplicate.

## ***Elemental Carbon/Organic Carbon***

Elemental carbon (EC) and organic carbon (OC) content of PM samples collected on pre-fired quartz filters was determined by NIOSH Method 5040 (NIOSH, 1994) using a Sunset Laboratory thermal evolution instrument. In this method, a 1.0 x 1.5 cm punch of the quartz filter sample is placed in the instrument, and organic and carbonate carbon are evolved in a helium atmosphere as the temperature is raised to 850 °C. Evolved carbon is catalytically oxidized to CO<sub>2</sub> in a bed of granular MnO<sub>2</sub>, then reduced to methane in a methanator. Methane is subsequently quantified by a flame ionization detector (FID). In a second stage, the sample oven temperature is reduced, an oxygen-helium mixture is introduced, and the temperature is increased to 940 °C. With the introduction of oxygen, pyrolytically generated carbon is oxidized and the transmittance of a laser light beam through the filter increases. The point at which the filter transmittance reaches its initial value is defined as the split between OC and EC. Carbon evolved prior to the split is considered OC (including carbonate), and carbon volatilized after the split is considered elemental (EC). Elemental carbon evolved is similarly oxidized to CO<sub>2</sub> and subsequently reduced to methane to be measured by the FID.

## ***Organic Compounds***

Individual organic compounds present in the fine PM collected on pre-fired quartz filters were determined by extracting the filters with hexane (two extractions) followed with a 2:1 mixture by volume of benzene and isopropanol (three extractions). Prior to extraction, the filters were composited as necessary to achieve a total of approximately 0.5 mg of OC and spiked with a mixture of deuterated internal recovery standards. These standards were selected to represent the range of expected solubilities, stabilities, chromatographic retention times, and volatilities of organic compounds present in the samples. All extracts from the five extraction steps were combined and concentrated using an automated nitrogen blow-down apparatus.

An aliquot of the combined extract was derivatized with diazomethane to yield methyl esters of any fatty acids which might be present. After the methylation reaction was complete,

the methylated extract aliquot was reconcentrated by nitrogen blowdown. A separate portion of the methylated extract was derivatized a second time using bis (trimethylsilyl) trifluoroacetamide-N,O-bis (trimethylsilyl) acetamide (Sylon BFT<sup>®</sup>) reagent to convert compounds such as levoglucosan and cholesterol to their trimethylsilyl (TMS) derivatives. Both derivatizations were performed in order to allow the compounds to be separated and eluted from a gas chromatograph column. Since the TMS derivatives are somewhat unstable over time, the silylation was carried out just prior to analysis.

Gas chromatography coupled with a mass spectrometer detector (GC/MS) was used to identify and quantify the individual organic compounds present in the extracts. A Hewlett-Packard 6890 GC equipped with an HP 5973 mass spectrometer detector was used. A 5MS column (30 m, 0.25 mm diameter, 0.25  $\mu$ m film thickness) was employed along with an injector temperature of 65 °C and a GC/MS interface temperature of 300 °C. The initial GC oven temperature was set at 65 °C with an initial hold time of 10 minutes. The oven temperature was then ramped upward at 10 °C/min to 300 °C and held at the upper temperature for an additional 41.5 minutes. Helium was used as the carrier gas (1 mL/min) and the GC was operated in the split/splitless mode.

Positive identification of target compounds was obtained by comparing mass spectra of the analytes with those obtained from over 100 authentic compound standards. Iso- and anteiso-alkanes were identified using secondary standards derived from paraffin candle wax. Additional compounds were identified as “probable” based on a comparison of the GC retention times and mass spectra with commercially available spectral libraries. Quantification of the individual compounds involved referencing each compound against one or more of the deuterated internal standards spiked into the sample to correct for losses of the analytes which may have occurred in the compositing, extracting, concentrating, and derivatizing steps. An extensive set of standards of target compounds at known concentrations, which also included the deuterated internal standard compounds, was used to establish 3-point or 5-point calibration curves from which the concentrations of the analytes were determined.

## ***Carbonyl Compounds***

Sep-Pak<sup>®</sup> chromatographic-grade silica gel cartridges impregnated with DNPH were used in series for carbonyl sample collection. The tubes were used in series to check for compound breakthrough. Following sample collection in the field, the cartridges and accompanying chain of custody documentation were transported to the ERG laboratory, where they were logged into the laboratory sample tracking system. The cartridges were extracted and analyzed for the compounds listed in Table 4-8 using EPA Compendium Method TO-11A, “Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC)” (EPA, 1999). The analytical instrument was a Varian 5000 HPLC with a multiwavelength detector operated at 360 nanometers (nm). The HPLC was configured with a 25 cm, 4.6 mm I.D., C18 silica analytical column with a 5- $\mu$ m particle size. An automatic sample injector was used to inject 25  $\mu$ L aliquots into the HPLC.

The chromatography data acquisition system was used to retrieve data from the HPLC. The data were processed and peak identifications were made using retention times and relative retention times determined by analysis of analytical standards. After peak identifications were made, the concentration of each target analyte was determined using individual response factors for the carbonyl compounds.

Daily calibration checks were performed to ensure that the analytical procedures were in control. Daily quality control checks were performed after every 10 samples on the days that samples were analyzed, with compound responses within  $\pm 15\%$  relative to the responses from the current calibration curve. Compound retention time drifts were also measured from the analysis of the quality control check sample and tracked to ensure that the HPLC was operating within acceptable parameters.

As part of the daily quality control check, if the analysis of the daily quality control sample was not acceptable, a second injection of the quality control standard was performed. If the second quality control check did not meet acceptance criteria or if more than one daily quality

**Table 4-8. Carbonyl Compounds Analyzed by High Performance Liquid Chromatography: Method Detection Limits**

Compound	CAS No.	Method Detection Limits μg
Formaldehyde	50-00-0	0.0838
Acetaldehyde	75-07-0	0.0916
Acetone	67-64-1	0.0428
Propionaldehyde	123-38-6	0.0934
Crotonaldehyde	4170-30-3	0.1283
Butyraldehyde	123-72-8	0.0956
Benzaldehyde	100-52-7	0.0959
Isovaleraldehyde	590-86-3	0.1076
Valeraldehyde	110-62-3	0.1758
<i>o</i> -Tolualdehyde	529-20-4	0.1439
<i>m</i> -Tolualdehyde	620-23-5	0.1439
<i>p</i> -Tolualdehyde	104-87-0	0.1439
Hexaldehyde	66-25-1	0.1377
2,5-Dimethylbenzaldehyde	5779-94-2	0.1337*
Diacetyl	432-03-8	0.0154*
Methacrolein	78-85-3	0.0125*
2-Butanone	78-93-3	0.0125*
Glyoxal	107-22-2	0.0412*
Acetophenone	98-86-2	0.0250*
Methylglyoxal	78-98-8	0.0244*
Octanal	124-13-0	0.0100*
Nonanal	124-19-6	0.0182*

\*Estimated value.

control check did not meet acceptance criteria, a new calibration curve (at five concentration levels) was analyzed. All samples analyzed with the unacceptable quality control checks would be re-analyzed.

An acetonitrile system blank was analyzed after the daily calibration check and before sample analysis. The system was considered in control if target analyte concentrations were less than the current method detection limits.

### ***Canister Analyses: Air Toxics and Speciated Nonmethane Organic Compounds***

The combined analysis for gas-phase air toxics and Speciated Nonmethane Organic Compounds was performed on a gas chromatograph(GC)/flame ionization detector(FID)/mass selective detector (MSD). A Hewlett-Packard 5971 MSD and a Hewlett-Packard 5890 Series II GC with a 60 m by 0.32 mm I.D. and a 1  $\mu\text{m}$  film thickness J&W DB-1 capillary column followed by a 2:1 splitter was used to send the larger portion of the column effluent to the MSD and the smaller fraction to the FID. The chromatograph oven containing the DB-1 capillary column was cooled to -50 °C with liquid nitrogen at the beginning of the sample injection. This temperature was held for 5 minutes and then increased at the rate of 15 °C per minute to 0 °C. The oven temperature was then ramped at 6 °C/minute to 150 °C, then ramped at 20 °C/minute to 225 °C and held for 8 minutes. The gas eluting from the DB-1 capillary column passed through the 2:1 fixed splitter, to divide the flow between the MSD and the FID.

The air toxics analysis was performed according to the procedures of EPA Compendium Method TO-15, “Determination of Volatile Organic Compounds (VOCs) In Air Collected in Specially-Prepared Canister and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS)” (U.S. EPA, 1999). The analysis of Speciated Nonmethane Organic Compounds was performed according to the procedures of “Technical Assistance Document for Sampling and Analysis of Ozone Precursors” (U.S. EPA, 1998). Detection limits for air toxics are shown in Table 4-9, and for the Speciated Nonmethane Organic Compounds in Table 4-10.

### ***Particle Size Distribution Data***

The SMPS was operated and collected data during both test days. Data were reduced using the TSI software package.

**Table 4-9. Detection Limits (ppbv) for Air Toxics Compounds  
(Analytical Method TO-15)**

Target Compounds*	CAS No.	Method Detection Limit $\mu\text{g}/\text{m}^3$
Acetylene	74-86-2	0.24
Propylene	115-07-1	0.17
Dichlorodifluoromethane	75-71-8	0.40
Chloromethane	74-87-3	0.24
Dichlorotetrafluoroethane	1320-37-2	0.70
Vinyl chloride	75-01-4	0.31
1,3-Butadiene	106-99-0	0.31
Bromomethane	74-83-9	0.70
Chloroethane	75-00-3	0.42
Acetonitrile	75-05-8	0.84
Acetone	67-64-1	1.23
Trichlorofluoromethane	75-69-4	0.45
Acrylonitrile	107-13-1	0.91
1,1-Dichloroethene	75-35-4	0.79
Methylene chloride	75-09-2	0.42
Trichlorotrifluoroethane	26523-64-8	1.07
<i>trans</i> -1,2-Dichloroethylene	56-60-5	0.47
1,1-Dichloroethane	75-34-3	0.65
Methyl <i>tert</i> -butyl ether	1634-04-1	1.29
Methyl ethyl ketone	78-93-3	0.88
Chloroprene	126-99-8	0.73
<i>cis</i> -1,3-Dichloroethylene	156-59-2	0.79
Bromochloromethane	74-97-5	1.26
Chloroform	67-66-3	0.49
Ethyl <i>tert</i> -butyl ether	637-92-3	1.25
1,2-Dichloroethane	107-06-2	0.48
1,1,1-Trichloroethane	71-55-6	0.65
Benzene	71-43-2	0.25
Carbon tetrachloride	56-23-5	1.01
<i>tert</i> -Amyl methyl ether	994-05-8	1.00

(Continued)



**Table 4-9. (Continued)**

<b>Target Compounds*</b>	<b>CAS No.</b>	<b>Method Detection Limit µg/m<sup>3</sup></b>
1,2-Dichloropropane	78-87-5	0.65
Ethyl acrylate	140-88-5	1.31
Bromodichloromethane	75-27-4	0.80
Trichloroethylene	79-01-6	0.75
Methyl methacrylate	80-62-6	1.47
<i>cis</i> -1,2-Dichloropropene	10061-01-5	0.82
Methyl isobutyl ketone	108-10-1	1.36
<i>trans</i> -1,2-Dichloropropene	10061-02-6	1.00
1,1,2-Trichloroethane	79-00-5	0.65
Toluene	108-88-3	0.45
Dibromochloromethane	124-48-1	1.36
1,2-Dibromoethane	106-93-4	1.23
<i>n</i> -Octane	111-65-9	0.56
Tetrachloroethylene	127-18-4	0.81
Chlorobenzene	108-90-7	0.55
Ethylbenzene	100-41-4	0.35
<i>m</i> -, <i>p</i> -Xylene	108-38-3/106-42-3	0.87
Bromoform	75-25-2	1.65
Styrene	100-42-5	0.59
1,1,2,2-Tetrachloroethane	79-34-5	0.82
<i>o</i> -Xylene	95-47-6	0.43
1,3,5-Trimethylbenzene	108-67-8	0.69
1,2,4-Trimethylbenzene	95-63-6	0.69
<i>m</i> -Dichlorobenzene	541-73-1	0.60
Chloromethylbenzene	100-44-7	0.72
<i>p</i> -Dichlorobenzene	106-46-7	1.08
<i>o</i> -Dichlorobenzene	95-50-1	0.72
1,2,4-Trichlorobenzene	120-82-1	0.89
Hexachloro-1,3-butadiene	87-68-3	1.28

\*MDLs are instrument detection limits based on Fed. Reg., 1984. MDLs reported here are based on nominal injection volume of 200 mL of gas.

**Table 4-10. Detection Limits ( $\mu\text{g}/\text{m}^3$ ) for Speciated Nonmethane Organic Compounds  
 (“Technical Assistance Document for Sampling and Analysis of Ozone Precursors”  
 (U.S. EPA, 1998))**

<b>Compound</b>	<b>CAS No.</b>	<b>Method Detection Limits <math>\mu\text{g}/\text{m}^3</math></b>
Ethylene	74-85-1	0.50
Acetylene	74-86-2	0.47
Ethane	74-84-0	0.54
Propylene	115-07-1	0.44
Propane	74-98-6	0.46
Propyne	74-99-7	0.42
Isobutane	75-28-5	0.43
Isobutene/1-butene	115-11-7/106-98-0	0.21
1,3-Butadiene	106-99-0	0.40
<i>n</i> -Butane	106-97-8	0.43
<i>trans</i> -2-Butene	624-64-6	0.42
<i>cis</i> -2-Butene	590-18-1	0.42
3-Methyl-1-butene	563-45-1	0.32
Isopentane	78-78-4	0.33
1-Pentene	109-67-1	0.32
2-Methyl-1-butene	563-46-2	0.45
<i>n</i> -Pentane	109-66-0	0.33
Isoprene	78-79-4	0.31
<i>trans</i> -2-Pentene	646-04-8	0.33
<i>cis</i> -2-Pentene	627-20-3	0.33
2-Methyl-2-butene	513-35-9	0.32
2,2-Dimethylbutane	75-83-2	0.46
Cyclopentene	142-29-0	0.31
4-Methyl-1-pentene	691-37-2	0.45
Cyclopentane	287-92-3	0.32
2,3-Dimethylbutane	79-29-8	0.46
2-Methylpentane	107-83-5	0.46
3-Methylpentane	96-14-0	0.46

(Continued)

**Table 4-10. (Continued)**

Compound	CAS No.	Method Detection Limits $\mu\text{g}/\text{m}^3$
2-Methyl-1-pentene	763-29-1	0.46
1-Hexene	592-41-6	0.46
2-Ethyl-1-butene	760-21-4	0.45
<i>n</i> -Hexane	110-54-3	0.46
<i>trans</i> -2-Hexene	4050-45-7	0.46
<i>cis</i> -2-Hexene	7688-21-3	0.46
Methylcyclopentane	96-37-7	0.45
2,4-Dimethylpentane	108-08-7	0.35
Benzene	71-43-2	0.42
Cyclohexane	110-82-7	0.45
2-Methylhexane	591-76-4	0.40
2,3-Dimethylpentane	565-59-3	0.40
3-Methylhexane	589-34-4	0.40
1-Heptene	592-76-7	0.39
2,2,4-Trimethylpentane	540-84-1	0.51
<i>n</i> -Heptane	142-82-5	0.40
Methylcyclohexane	108-87-2	0.39
2,2,3-Trimethylpentane	564-02-3	0.51
2,3,4-Trimethylpentane	565-75-3	0.51
Toluene	108-88-3	0.37
2-Methylheptane	592-27-8	0.51
3-Methylheptane	589-81-1	0.51
1-Octene	111-66-0	0.50
<i>n</i> -Octane	111-65-9	0.51
Ethylbenzene	100-41-4	0.52
<i>m</i> -, <i>p</i> -Xylene	108-38-3/106-42-3	0.47
Styrene	100-42-5	0.46
<i>o</i> -Xylene	95-47-6	0.47
1-Nonene	124-11-8	0.40
<i>n</i> -Nonane	111-84-2	0.41

(Continued)

**Table 4-10. (Continued)**

Compound	CAS No.	Method Detection Limits
		$\mu\text{g}/\text{m}^3$
Isopropylbenzene	98-82-8	0.38
$\alpha$ -Pinene	80-56-8	0.39
<i>n</i> -Propylbenzene	103-65-1	0.38
<i>m</i> -Ethyltoluene	620-14-4	0.38
<i>p</i> -Ethyltoluene	622-96-8	0.38
1,3,5-Trimethylbenzene	108-67-8	0.38
<i>o</i> -Ethyltoluene	611-14-3	0.38
$\beta$ -Pinene	127-91-3	0.39
1,2,4-Trimethylbenzene	95-63-6	0.38
1-Decene	872-05-9	0.33
<i>n</i> -Decane	124-18-5	0.33
1,2,3-Trimethylbenzene	526-73-8	0.38
<i>m</i> -Diethylbenzene	141-93-5	0.32
<i>p</i> -Diethylbenzene	105-05-5	0.32
1-Undecene	821-95-4	0.49
<i>n</i> -Undecane	1120-21-4	0.50
1-Dodecene	112-41-4	0.49
<i>n</i> -Dodecane	112-40-3	0.50
1-Tridecene	2437-56-1	0.49
<i>n</i> -Tridecane	629-50-5	0.50

## **Section 5**

### **Results and Discussion**

Analyses were performed in different laboratories according to the scheme shown in Table 3-1, with the analytical procedures described in Section 4. Results of these analyses are discussed in this section.

#### **PM Mass, Elemental/Organic Carbon, Major Inorganic Ions, and Major Elements**

Emissions of elemental/organic carbon (EC/OC), major elements, and major inorganic ions as components of the fine particulate matter are reported in Table 5-1 as weight percent of measured PM-2.5 mass. Results tabulated in Table 5-1 also indicate a nearly three-fold range of PM-2.5 mass emission rates between the two days of testing. However, the absolute mass emission rates of PM-2.5 were quite low (3.54 and 1.23 mg/kg fuel) on both days.

EC/OC values for samples collected on quartz filters with and without an XAD-coated annular denuder fronting the filters exhibited a wide variance. Substantially lower OC values were found on the filters fronted with an organic denuder than on filters without a preceding denuder. It is likely that much of the OC collected on the quartz filters without a denuder in place represents adsorbed gas-phase semivolatile organic compounds.

Of the major water-soluble ions, only sulfate and potassium ions were above quantitation limits. Total potassium as measured by X-ray fluorescence spectrometry agreed well with water-soluble potassium determined by ion chromatography. Silicon was the element found in greatest concentration, perhaps originating from the firebrick lining of the boiler. Supporting data for the inorganic analyses are found in Appendices B through E.

**Table 5-1. Fine Particle Emission Rate and Fine Particle Chemical Composition of Emissions from an Industrial Wood-Fired Boiler, Including Gas-Phase Volatile Organic and Carbonyl Compounds**

PM-2.5 Emission Rate (mg/kg fuel burned)	1.23 - 3.54 <sup>a</sup>	
Speciated Carbonyl Compounds Emission Rate (mg/kg fuel burned)	2.53 (Day 1)	0.80 (Day 2)
Total Carbonyl Compound Emission Rate (mg/kg fuel burned)	2.74 (Day 1)	0.94 (Day 2)
Speciated NMOC Emission Rate (mg/kg fuel burned)	4.83 (Day 1)	0.98 (Day 2)
Total NMOC Emission Rate (mg/kg fuel burned)	7.50 (Day 1)	1.85 (Day 2)
Elemental and Organic Carbon (Wt.% of Measured PM-2.5 Mass)	w/out denuder <sup>b</sup>	w/ denuder <sup>c</sup>
Elemental Carbon	3.0 ± 0.4	13.8 ± 3.1
Organic Carbon	84.6 ± 11.0	32.6 ± 8.0
Ionic Species (Wt.% of Measured PM-2.5 Mass) <sup>d</sup>		
Chloride	NQ	
Nitrate	NQ	
Sulfate	7.8 ± 0.6	
Potassium	6.6 ± 0.5	
Magnesium	ND	
Calcium	ND	
Elemental Composition (Wt.% of Measured PM-2.5 Mass) <sup>e</sup>		
Sodium	0.18 ± 0.04	
Magnesium	0.17 ± 0.01	
Silicon	16.2 ± 2.5	
Phosphorus	0.09 ± 0.03	
Sulfur	3.7 ± 0.4	
Chlorine	0.64 ± 0.04	
Potassium	10.6 ± 0.6	
Calcium	0.76 ± 0.06	

NQ-below quantitation limits

ND-below detection limits

a) range over two test days

b) average of two filters, one from each day of testing

c) average of two filters, one from each day of testing

d) average of two filters from each day of testing with the exception of sulfate, which was below quantitation limits on the second day

e) average of two filters from the first day of testing

Error shown is the standard deviation of the results from the individual filters.

## **Speciated Particle-Phase (PM-2.5) Organic Compounds**

Table 5-2(a, b) reports the emission rates ( $\mu\text{g/kg}$  of fuel) of individual organic compounds collected on the organic denuders, quartz filters, and PUF plugs in the sampling arrays. Compounds attributed to the particle-phase are also reported as weight percent of measured PM-2.5 mass. For the denuder/filter/PUF sampling arrays (Table 5-2a), organic compounds attributed to the particulate matter were those collected on the quartz filters and on the following PUF plugs. For the undenuded arrays (Table 5-2b), only the organic compounds found on the quartz filters were attributed to the particulate matter. Because of very low PM-2.5 mass loadings collected on individual filters, it was necessary to composite a number of quartz filters from different sampling arrays between the two test days to have sufficient material to quantify individual organic compounds. Organic compound speciation results reported in Table 5-2(a, b) therefore represent a composite over the two days. Minor variations in the stack gas and sampling flow rates which occurred between the two days have been factored into the calculations to determine the reported emission rates. Supporting data for these analyses are included in Appendix F.

## **Gas-Phase Carbonyl Compounds**

Analytical results for the carbonyl field samples for each of the two test days are shown in Table 5-3(a, b). Results of the analysis are reported for the sum of the paired DNPH-impregnated silica gel tubes since the tubes were sampled as pairs, using the back tube as a check for breakthrough. At the bottom of the table, the entry reported as “Total Unspeciated” is the total mass (front plus back tube) of the compounds characterized as carbonyl compounds but not identified as a specific compound because no analytical standard was available. The entry reported as “Total Speciated + Unspeciated” includes the total mass (front and back tube) of both specifically identified carbonyl compounds and unspeciated carbonyl compounds. As Table 5-3 shows, the largest portion of the carbonyl compounds ( $>75\%$ ) consisted of speciated (i.e., specifically identified) carbonyl compounds. Supporting data showing results for each individual carbonyl sampling tube (front and back) are included in Appendix G.

**Table 5-2a. Gas- and Particle-Phase Organic Compounds as Measured by Denuder-Quartz Filter-PUF**

Compound	Denuder (mg/kg of fuel)	Quartz filter (mg/kg of fuel)	PUFs 1 and 2 (mg/kg of fuel)	% PM <sub>2.5</sub> Mass
Naphthalene	0.30	ND	2.28	0.048 ± 0.006
Acenaphthylene	ND	ND	ND	ND
Acenaphthene	ND	ND	0.54	0.011 ± 0.003
Fluorene	ND	ND	2.01	0.042 ± 0.0003
Phenanthrene	0.24	ND	1.94	0.041 ± 0.009
Anthracene	ND	ND	ND	ND
Fluoranthene	ND	0.01	0.21	0.005 ± 0.0004
Pyrene	ND	ND	0.09	0.002 ± 0.00008
Benzo[a]anthracene	ND	ND	ND	ND
Chrysene	ND	ND	ND	ND
Benzo[b]fluoranthene	ND	ND	ND	ND
Benzo[k]fluoranthene	ND	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND	ND
Benzo[ghi]perylene	ND	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND	ND
Indeno[1,2,3-cd]fluoranthene	ND	ND	ND	ND
Dibenzo[a,h]anthracene	ND	ND	ND	ND
Coronene	ND	ND	ND	ND
1-Methylnaphthalene	ND	ND	3.12	0.065 ± 0.010
2-Methylnaphthalene	ND	ND	4.24	0.089 ± 0.047
2,7-Dimethylnaphthalene	ND	ND	0.69	0.014 ± 0.002
1,3-Dimethylnaphthalene	ND	ND	2.40	0.050 ± 0.008
2,6-Dimethylnaphthalene	ND	ND	1.88	0.040 ± 0.006
9-Methylanthracene	ND	ND	ND	ND
Methylfluorene	ND	ND	1.35	0.028 ± 0.004
bis(2-Ethylhexyl)phthalate	1.59	0.19	4.09	0.090 ± 0.019
Butyl benzyl phthalate	8.04	ND	4.48	0.094 ± 0.052
Diethyl phthalate	1.45	ND	31.06	0.651 ± 0.221
Dimethyl phthalate	0.33	ND	20.80	0.436 ± 0.045
Di- <i>n</i> -butyl phthalate	0.63	ND	1.20	0.025 ± 0.014
Di- <i>n</i> -octyl phthalate	ND	ND	ND	ND
Octylcyclohexane	ND	ND	ND	ND
Decylcyclohexane	ND	ND	ND	ND

ND = Compound not detected.

(Continued)



**Table 5-2a. (Continued)**

Compound	Denuder (mg/kg of fuel)	Quartz filter (mg/kg of fuel)	PUFs 1 and 2 (mg/kg of fuel)	% PM <sub>2.5</sub> Mass
Tridecylcyclohexane	ND	ND	ND	ND
Nonadecylcyclohexane	ND	ND	ND	ND
Norpristane	ND	ND	ND	ND
Pristane	ND	ND	ND	ND
Phytane	ND	ND	ND	ND
Squalane	ND	ND	ND	ND
ABB-20R-C27-Cholestane	ND	ND	ND	ND
BAA-20R-C27-Cholestane	ND	ND	ND	ND
AAA-20S-C27-Cholestane	ND	ND	ND	ND
AAA-20R-C27-Cholestane	ND	ND	ND	ND
ABB-20R-C28-Methylcholestane	ND	ND	ND	ND
ABB-20R-C29-Ethylcholestane	ND	ND	ND	ND
17A(H)-22, 29, 30-Trisnorhopane	ND	ND	ND	ND
17B(H)-21A(H)-30-Norhopane	ND	ND	ND	ND
17B(H)-21B(H)-Hopane	ND	ND	ND	ND
17B(H)-21A(H)-Hopane	ND	ND	ND	ND
17A(H)-21B(H)-Hopane	ND	ND	ND	ND
<i>n</i> -Decane (C10)	ND	ND	ND	ND
<i>n</i> -Undecane (C11)	ND	ND	ND	ND
<i>n</i> -Dodecane (C12)	3.94	ND	ND	ND
<i>n</i> -Tridecane (C13)	0.60	ND	ND	ND
<i>n</i> -Tetradecane (C14)	3.00	ND	ND	ND
<i>n</i> -Pentadecane (C15)	0.89	ND	1.80	0.038 ± 0.033
<i>n</i> -Hexadecane (C16)	2.06	ND	4.51	0.095 ± 0.057
<i>n</i> -Heptadecane (C17)	1.00	ND	2.98	0.062 ± 0.009
<i>n</i> -Octadecane (C18)	0.77	ND	4.47	0.094 ± 0.013
<i>n</i> -Nonadecane (C19)	1.77	ND	10.58	0.222 ± 0.028
<i>n</i> -Eicosane (C20)	5.60	ND	1.04	0.022 ± 0.003
<i>n</i> -Heneicosane (C21)	18.96	ND	2.74	0.057 ± 0.007
<i>n</i> -Docosane (C22)	160.29	ND	ND	ND
<i>n</i> -Tricosane (C23)	550.25	2.83	18.90	0.456 ± 0.086
<i>n</i> -Tetracosane (C24)	78.12	19.88	1.68	0.452 ± 0.085
<i>n</i> -Pentacosane (C25)	32.86	39.68	5.33	0.944 ± 0.178
<i>n</i> -Hexacosane (C26)	12.37	44.01	4.53	1.018 ± 0.192

ND = Compound not detected.

(Continued)

Table 5-2a. (Continued)

Compound	Denuder (mg/kg of fuel)	Quartz filter (mg/kg of fuel)	PUFs 1 and 2 (mg/kg of fuel)	% PM <sub>2.5</sub> Mass
<i>n</i> -Heptacosane (C27)	7.37	28.78	5.74	0.724 ± 0.137
<i>n</i> -Octacosane (C28)	6.29	17.00	2.45	0.408 ± 0.144
<i>n</i> -Nonacosane (C29)	3.38	7.62	3.58	0.235 ± 0.083
<i>n</i> -Triacontane (C30)	1.12	3.88	1.11	0.104 ± 0.032
<i>n</i> -Hentriacontane (C31)	0.67	2.26	1.51	0.079 ± 0.025
<i>n</i> -Dotriacontane (C32)	0.79	0.78	3.09	0.081 ± 0.020
<i>n</i> -Tritriacontane (C33)	0.46	0.27	1.28	0.033 ± 0.010
<i>n</i> -Tetratriacontane (C34)	0.30	0.11	2.77	0.060 ± 0.019
<i>n</i> -Pentatriacontane (C35)	0.94	0.24	2.79	0.064 ± 0.020
<i>n</i> -Hexatriacontane (C36)	ND	0.08	ND	0.002 ± 0.0006
<i>n</i> -Tetracontane (C40)	ND	ND	ND	ND
3-Methylnonadecane	0.33	ND	ND	ND
2-Methylnonadecane	1.70	ND	ND	ND
Cyclopenta[cd]pyrene	ND	ND	ND	ND
Dibenzo[a,e]pyrene	ND	ND	ND	ND
Pyrene	ND	ND	0.09	0.002 ± 0.0002
Benzo[a]pyrene	ND	ND	ND	ND
Methylfluoranthene	ND	ND	ND	ND
Methylchrysene	ND	ND	ND	ND
Retene	ND	ND	ND	ND
Anthroquinone	ND	ND	ND	ND
9-Fluorenone	ND	ND	1.34	0.028 ± 0.006
Benzo[a]anthracene-7,12-dione	ND	ND	ND	ND
1,8-Naphthalic anhydride	ND	ND	ND	ND
Squalene	2.65	ND	ND	ND
1-Octadecene	1.15	ND	ND	ND
Benzo[e]pyrene	ND	ND	ND	ND
Oxalic acid (C2)	ND	ND	ND	ND
Malonic acid (C3)	ND	ND	ND	ND
Maleic acid (C3=)	ND	ND	ND	ND
Fumaric acid (C4=)	ND	ND	ND	ND
Succinic acid (C4) Butanedioic acid	ND	ND	ND	ND
Glutaric acid (C5) Pentanedioic acid	ND	ND	ND	ND
Adipic acid (C6) Hexanedioic acid	ND	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table 5-2a. (Continued)**

<b>Compound</b>	<b>Denuder (mg/kg of fuel)</b>	<b>Quartz filter (mg/kg of fuel)</b>	<b>PUFs 1 and 2 (mg/kg of fuel)</b>	<b>% PM<sub>2.5</sub> Mass</b>
Pimelic acid (C7) Heptanedioic acid	ND	ND	ND	ND
Suberic acid (C8) Octanedioic acid	ND	ND	ND	ND
Azelaic acid (C9) Nonanedioic acid	ND	ND	ND	ND
Sebacic acid (C10) Decanedioic acid	ND	ND	ND	ND
Phthalic acid (1,2)	3.14	ND	ND	ND
Isophthalic acid (1,3)	5.39	ND	ND	ND
Terephthalic acid (1,4)	ND	ND	2.37	0.050 ± 0.015
1,2,4-Benzenetricarboxylic acid	ND	ND	ND	ND
1,2,4,5-Benzenetetracarboxylic acid	ND	ND	ND	ND
Methylphthalic acid	ND	ND	ND	ND
C6 Hexanoic acid	ND	ND	ND	ND
C8 Octanoic acid	0.29	ND	2.91	0.061 ± 0.014
C9 Nonanoic acid	0.63	ND	2.76	0.058 ± 0.013
C10 Decanoic acid	1.02	ND	ND	ND
C11 Undecanoic acid	0.69	ND	0.48	0.010 ± 0.005
C12 Dodecanoic acid	2.11	ND	1.20	0.025 ± 0.004
C13 Tridecanoic Acid	1.09	0.06	0.19	0.005 ± 0.0007
C14 Tetradecanoic acid	2.78	ND	1.08	0.023 ± 0.003
C15 Pentadecanoic Acid	0.95	ND	0.34	0.007 ± 0.001
C16 Hexadecanoic acid	16.34	1.73	2.03	0.079 ± 0.012
C17 Heptadecanoic Acid	ND	ND	0.26	0.005 ± 0.0007
C18 Octadecanoic acid	10.10	5.39	ND	0.113 ± 0.017
C19 Nonadecanoic Acid	ND	ND	0.01	0.000
C20 Eicosanoic acid	ND	0.21	ND	0.004 ± 0.0006
C21 Heneicosanoic Acid	ND	ND	ND	ND
C22 Docosanoic acid	ND	ND	0.07	0.001 ± 0.0001
C23 Tricosanoic Acid	ND	ND	ND	ND
C24 Tetracosanoic acid	0.25	ND	ND	ND
C25 Pentacosanoic Acid	ND	ND	ND	ND
C26 Hexacosanoic Acid	ND	ND	ND	ND
C27 Heptacosanoic Acid	ND	ND	ND	ND
Abietic acid	ND	ND	ND	ND
Octacosanoic acid	ND	ND	0.04	0.001 ± 0.0001
Nonacosanoic Acid	ND	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table 5-2a. (Continued)**

Compound	Denuder (mg/kg of fuel)	Quartz filter (mg/kg of fuel)	PUFs 1 and 2 (mg/kg of fuel)	% PM <sub>2.5</sub> Mass
Triacontanoic acid	ND	ND	ND	ND
Pinonic acid	ND	ND	ND	ND
Palmitoleic acid (C16:1)	0.76	0.04	ND	0.001 ± 0.0001
Oleic acid (C18:1)	ND	0.21	ND	0.004 ± 0.0006
Linoleic acid (C18:2)	ND	0.11	ND	0.002 ± 0.0001
Linolenic acid	ND	ND	ND	ND
Pimaric acid	43.00	ND	ND	ND
Sandaracopimaric acid	ND	ND	ND	ND
Isopimaric acid	ND	ND	ND	ND
6,8,11,13-Abietatetraen-18-oic acid	ND	ND	ND	ND
Dehydroabietic acid	ND	ND	ND	ND
Levogluconan (TMS derivative)	ND	0.88	ND	0.018 ± 0.011
Cholesterol (TMS derivative)	ND	2.09	ND	0.044 ± 0.004
Stigmasterol (TMS derivative)	ND	2.92	ND	0.061 ± 0.005
Monopalmitin (TMS derivative)	ND	0.33	ND	0.007 ± 0.001
Monoolein (TMS derivative)	ND	0.92	ND	0.019 ± 0.002
Monostearin (TMS derivative)	ND	1.47	ND	0.031 ± 0.002
Glycerine (TMS derivative)	ND	0.86	ND	0.018 ± 0.003
β-Sitosterol (TMS derivative)	ND	ND	ND	ND
Sitostenone (TMS derivative)	ND	ND	ND	ND
α-Amyrin	ND	ND	ND	ND
β-Amyrin	ND	ND	ND	ND
iso-Docosane	ND	ND	ND	ND
anteiso-Docosane	0.68	ND	ND	ND
iso-Tricosane	1.41	ND	ND	ND
anteiso-Tricosane	6.44	ND	ND	ND
iso-Tetracosane	0.83	1.01	ND	0.021 ± 0.004
anteiso-Tetracosane	0.74	0.43	ND	0.009 ± 0.002
iso-Pentacosane	0.56	2.49	ND	0.052 ± 0.010
anteiso-Pentacosane	0.77	1.51	ND	0.032 ± 0.006
iso-Hexacosane	0.44	2.34	ND	0.049 ± 0.009
anteiso-Hexacosane	0.56	1.91	ND	0.040 ± 0.008
iso-Heptacosane	0.10	1.73	ND	0.036 ± 0.007
anteiso-Heptacosane	0.18	1.41	ND	0.030 ± 0.006

ND = Compound not detected.

(Continued)

**Table 5-2a. (Continued)**

<b>Compound</b>	<b>Denuder (mg/kg of fuel)</b>	<b>Quartz filter (mg/kg of fuel)</b>	<b>PUFs 1 and 2 (mg/kg of fuel)</b>	<b>% PM<sub>2.5</sub> Mass</b>
iso-Octacosane	ND	0.77	ND	0.016 ± 0.003
anteiso-Octacosane	ND	0.80	ND	0.017 ± 0.003
iso-Nonacosane	0.38	0.43	ND	0.009 ± 0.003
anteiso-Nonacosane	0.54	0.31	ND	0.007 ± 0.002
iso-Triacontane	ND	0.28	ND	0.006 ± 0.002
anteiso-Triacontane	ND	0.22	ND	0.005 ± 0.002
iso-Hentriacontane	ND	0.10	ND	0.002 ± 0.0006
anteiso-Hentriacontane	ND	0.07	ND	0.001 ± 0.0003
iso-Dotriacontane	ND	0.06	ND	0.001 ± 0.0003
anteiso-Dotriacontane	ND	0.04	ND	0.001 ± 0.003
iso-Tritriacontane	ND	ND	ND	ND
anteiso-Tritriacontane	ND	ND	ND	ND
ND = Compound not detected.				

**Table 5-2b. Gas- and Particle-Phase Organic Compounds as Measured by Quartz Filter-PUF-PUF**

Compound	Quartz filter (mg/kg of fuel)	PUFs 1 and 2 (mg/kg of fuel)	% PM <sub>2.5</sub> Mass
Naphthalene	ND	1.49	ND
Acenaphthylene	ND	ND	ND
Acenaphthene	ND	0.85	ND
Fluorene	ND	2.65	ND
Phenanthrene	ND	ND	ND
Anthracene	ND	ND	ND
Fluoranthene	0.01	ND	0.0002 ± 0.0001
Pyrene	ND	ND	ND
Benzo[a]anthracene	ND	ND	ND
Chrysene	ND	ND	ND
Benzo[b]fluoranthene	ND	ND	ND
Benzo[k]fluoranthene	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND
Benzo[ghi]perylene	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND
Indeno[1,2,3-cd]fluoranthene	ND	ND	ND
Dibenzo[a,h]anthracene	ND	ND	ND
Coronene	ND	ND	ND
1-Methylnaphthalene	ND	2.81	ND
2-Methylnaphthalene	ND	3.49	ND
2,7-Dimethylnaphthalene	ND	1.67	ND
1,3-Dimethylnaphthalene	ND	2.39	ND
2,6-Dimethylnaphthalene	ND	2.37	ND
9-Methylanthracene	0.06	ND	0.0012 ± 0.00004
Methylfluorene	0.00	ND	0.0000
bis(2-Ethylhexyl)phthalate	0.57	3.75	0.0119 ± 0.0025
Butyl benzyl phthalate	ND	ND	ND
Diethyl phthalate	ND	19.10	ND
Dimethyl phthalate	ND	20.79	ND
Di- <i>n</i> -butyl phthalate	ND	ND	ND
Di- <i>n</i> -octyl phthalate	ND	0.29	ND
Octylcyclohexane	ND	ND	ND
Decylcyclohexane	ND	ND	ND
Tridecylcyclohexane	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table 5-2b. (Continued)**

<b>Compound</b>	<b>Quartz filter (mg/kg of fuel)</b>	<b>PUFs 1 and 2 (mg/kg of fuel)</b>	<b>% PM<sub>2.5</sub> Mass</b>
Nonadecylcyclohexane	ND	ND	ND
Norpristane	ND	ND	ND
Pristane	ND	ND	ND
Phytane	ND	ND	ND
Squalane	ND	ND	ND
ABB-20R-C27-Cholestane	ND	ND	ND
BAA-20R-C27-Cholestane	ND	ND	ND
AAA-20S-C27-Cholestane	ND	ND	ND
AAA-20R-C27-Cholestane	ND	ND	ND
ABB-20R-C28-Methylcholestane	ND	ND	ND
ABB-20R-C29-Ethylcholestane	ND	ND	ND
17A(H)-22, 29, 30-Trisnorhopane	ND	ND	ND
17B(H)-21A(H)-30-Norhopane	ND	ND	ND
17B(H)-21B(H)-Hopane	ND	ND	ND
17B(H)-21A(H)-Hopane	ND	ND	ND
17A(H)-21B(H)-Hopane	ND	ND	ND
<i>n</i> -Decane (C10)	ND	1.67	ND
<i>n</i> -Undecane (C11)	ND	3.30	ND
<i>n</i> -Dodecane (C12)	ND	ND	ND
<i>n</i> -Tridecane (C13)	ND	ND	ND
<i>n</i> -Tetradecane (C14)	ND	ND	ND
<i>n</i> -Pentadecane (C15)	ND	1.02	ND
<i>n</i> -Hexadecane (C16)	ND	2.66	ND
<i>n</i> -Heptadecane (C17)	ND	3.49	ND
<i>n</i> -Octadecane (C18)	ND	7.74	ND
<i>n</i> -Nonadecane (C19)	ND	14.24	ND
<i>n</i> -Eicosane (C20)	ND	9.83	ND
<i>n</i> -Heneicosane (C21)	ND	23.16	ND
<i>n</i> -Docosane (C22)	2.81	64.75	0.0588 ± 0.011
<i>n</i> -Tricosane (C23)	17.68	88.86	0.3707 ± 0.070
<i>n</i> -Tetracosane (C24)	47.75	16.15	1.0010 ± 0.189
<i>n</i> -Pentacosane (C25)	59.37	5.11	1.2446 ± 0.235
<i>n</i> -Hexacosane (C26)	57.32	6.17	1.2016 ± 0.227
<i>n</i> -Heptacosane (C27)	36.98	12.07	0.7752 ± 0.146
<i>n</i> -Octacosane (C28)	22.74	15.87	0.4767 ± 0.16

ND = Compound not detected.

(Continued)

**Table 5-2b. (Continued)**

Compound	Quartz filter (mg/kg of fuel)	PUFs 1 and 2 (mg/kg of fuel)	% PM <sub>2.5</sub> Mass
<i>n</i> -Nonacosane (C29)	10.86	7.04	0.2276 ± 0.081
<i>n</i> -Triacontane (C30)	7.58	3.90	0.1590 ± 0.056
<i>n</i> -Hentriacontane (C31)	4.01	1.55	0.0841 ± 0.0212
<i>n</i> -Dotriacontane (C32)	1.55	0.50	0.0326 ± 0.0082
<i>n</i> -Tritriacontane (C33)	0.64	0.08	0.0134 ± 0.0034
<i>n</i> -Tetratriacontane (C34)	0.23	ND	0.0049 ± 0.0012
<i>n</i> -Pentatriacontane (C35)	0.33	ND	0.0068 ± 0.0017
<i>n</i> -Hexatriacontane (C36)	0.20	ND	0.0042 ± 0.0011
<i>n</i> -Tetracontane (C40)	ND	ND	ND
3-Methylnonadecane	ND	1.58	ND
2-Methylnonadecane	ND	1.51	ND
Cyclopenta[cd]pyrene	ND	ND	ND
Dibenzo[a,e]pyrene	ND	ND	ND
Pyrene	ND	0.05	ND
Benzo[a]pyrene	ND	ND	ND
Methylfluoranthene	ND	ND	ND
Methylchrysene	ND	ND	ND
Retene	ND	ND	ND
Anthroquinone	ND	ND	ND
9-Fluorenone	ND	ND	ND
Benzo[a]anthracene-7,12-dione	ND	ND	ND
1,8-Naphthalic anhydride	ND	ND	ND
Squalene	ND	ND	ND
1-Octadecene	ND	ND	ND
Benzo[e]pyrene	ND	ND	ND
Oxalic acid (C2)	0.06	ND	0.0012 ± 0.0005
Malonic acid (C3)	ND	ND	ND
Maleic acid (C3=)	ND	ND	ND
Fumaric acid (C4=)	ND	ND	ND
Succinic acid (C4) Butanedioic acid	ND	ND	ND
Glutaric acid (C5) Pentanedioic acid	ND	ND	ND
Adipic acid (C6) Hexanedioic acid	ND	ND	ND
Pimelic acid (C7) Heptanedioic acid	ND	ND	ND
Suberic acid (C8) Octanedioic acid	ND	ND	ND
Azelaic acid (C9) Nonanedioic acid	ND	ND	ND

ND = Compound not detected.

(Continued)



**Table 5-2b. (Continued)**

<b>Compound</b>	<b>Quartz filter (mg/kg of fuel)</b>	<b>PUFs 1 and 2 (mg/kg of fuel)</b>	<b>% PM<sub>2.5</sub> Mass</b>
Sebacic acid (C10) Decanedioic acid	ND	ND	ND
Phthalic acid (1,2)	ND	ND	ND
Isophthalic acid (1,3)	ND	ND	ND
Terephthalic acid (1,4)	ND	ND	ND
1,2,4-Benzenetricarboxylic acid	ND	ND	ND
1,2,4,5-Benzenetetracarboxylic acid	ND	ND	ND
Methylphthalic acid	ND	ND	ND
C6 Hexanoic acid	ND	ND	ND
C8 Octanoic acid	ND	3.21	ND
C9 Nonanoic acid	0.01	2.91	0.0003 ± 0.00007
C10 Decanoic acid	0.04	3.51	0.0009 ± 0.0005
C11 Undecanoic acid	0.00	0.85	0.0000
C12 Dodecanoic acid	ND	1.53	ND
C13 Tridecanoic Acid	0.06	0.27	0.0014 ± 0.0002
C14 Tetradecanoic acid	0.37	1.10	0.0078 ± 0.0012
C15 Pentadecanoic Acid	0.24	0.05	0.0051 ± 0.0008
C16 Hexadecanoic acid	11.09	2.15	0.2325 ± 0.0346
C17 Heptadecanoic Acid	ND	ND	ND
C18 Octadecanoic acid	10.66	0.68	0.2235 ± 0.0333
C19 Nonadecanoic Acid	ND	ND	ND
C20 Eicosanoic acid	0.38	0.03	0.0079 ± 0.0012
C21 Heneicosanoic Acid	ND	ND	ND
C22 Docosanoic acid	ND	0.18	ND
C23 Tricosanoic Acid	ND	0.00	ND
C24 Tetracosanoic acid	ND	0.02	ND
C25 Pentacosanoic Acid	ND	0.09	ND
C26 Hexacosanoic Acid	ND	0.04	ND
C27 Heptacosanoic Acid	ND	ND	ND
Abietic acid	ND	ND	ND
C28 Octacosanoic acid	ND	0.12	ND
C29 Nonacosanoic Acid	ND	ND	ND
C30 Triacontanoic acid	ND	ND	ND
Pinonic acid	2.57	ND	0.0538 ± 0.0169
Palmitoleic acid (C16:1)	0.08	0.29	0.0018 ± 0.0004
Oleic acid (C18:1)	0.90	ND	0.0189 ± 0.0029

ND = Compound not detected.

(Continued)

**Table 5-2b. (Continued)**

<b>Compound</b>	<b>Quartz filter (mg/kg of fuel)</b>	<b>PUFs 1 and 2 (mg/kg of fuel)</b>	<b>% PM<sub>2.5</sub> Mass</b>
Linoleic acid (C18:2)	0.44	ND	0.0092 ± 0.0012
Linolenic acid	ND	ND	ND
Pimaric acid	ND	ND	ND
Sandaracopimaric acid	ND	ND	ND
Isopimaric acid	ND	ND	ND
6,8,11,13-Abietatetraen-18-oic acid	ND	ND	ND
Dehydroabietic acid	ND	38.75	ND
Levoglucosan (TMS derivative)	0.06	ND	0.0013 ± 0.0008
Cholesterol (TMS derivative)	ND	ND	ND
Stigmasterol (TMS derivative)	ND	ND	ND
Monopalmitin (TMS derivative)	0.06	ND	0.0013 ± 0.0002
Monoolein (TMS derivative)	ND	ND	ND
Monostearin (TMS derivative)	1.08	ND	0.0226 ± 0.0018
Glycerine (TMS derivative)	ND	ND	ND
β-Sitosterol (TMS derivative)	ND	ND	ND
Sitostenone (TMS derivative)	ND	ND	ND
α-Amyrin	ND	ND	ND
β-Amyrin	ND	ND	ND
iso-Docosane	ND	ND	ND
anteiso-Docosane	ND	ND	ND
iso-Tricosane	ND	ND	ND
anteiso-Tricosane	ND	ND	ND
iso-Tetracosane	2.03	ND	0.0426 ± 0.0081
anteiso-Tetracosane	0.90	ND	0.0188 ± 0.0036
iso-Pentacosane	3.45	ND	0.0722 ± 0.0136
anteiso-Pentacosane	2.12	ND	0.0444 ± 0.0084
iso-Hexacosane	2.95	ND	0.0618 ± 0.0117
anteiso-Hexacosane	2.30	ND	0.0483 ± 0.0091
iso-Heptacosane	2.49	ND	0.0523 ± 0.0099
anteiso-Heptacosane	1.90	ND	0.0398 ± 0.0075
iso-Octacosane	1.34	ND	0.0282 ± 0.0053
anteiso-Octacosane	0.99	ND	0.0207 ± 0.0039
iso-Nonacosane	0.64	ND	0.0134 ± 0.0025
anteiso-Nonacosane	0.47	ND	0.0098 ± 0.0019
iso-Triacontane	0.43	ND	0.0089 ± 0.0017

ND = Compound not detected.

(Continued)

**Table 5-2b. (Continued)**

<b>Compound</b>	<b>Quartz filter (mg/kg of fuel)</b>	<b>PUFs 1 and 2 (mg/kg of fuel)</b>	<b>% PM<sub>2.5</sub> Mass</b>
anteiso-Triacontane	0.27	ND	0.0058 ± 0.0011
iso-Hentriacontane	0.21	ND	0.0044 ± 0.0008
anteiso-Hentriacontane	0.14	ND	0.0030 ± 0.0006
iso-Dotriacontane	0.09	ND	0.0020 ± 0.0004
anteiso-Dotriacontane	0.08	ND	0.0017 ± 0.003
iso-Tritriacontane	ND	ND	ND
anteiso-Tritriacontane	ND	ND	ND

ND = Compound not detected.

**Table 5-3a. Carbonyl Compounds Analyzed by High Performance Liquid Chromatography Field Samples, August 8, 2000**

Compound	CAS No.	Res. Chamber Pair $\mu\text{g}$	Blank $\mu\text{g}$	Corrected Value	% Total <sup>a</sup>
formaldehyde	50-00-0	36.35	0.04	$36.31 \pm 4.00$	$63.051 \pm 6.948$
acetaldehyde	75-07-0	6.82	0.18	$6.64 \pm 0.08$	$11.532 \pm 0.131$
acetone	67-64-1	2.97	ND <sup>b</sup>	$2.97 \pm 0.13$	$5.164 \pm 0.218$
propionaldehyde	123-38-6	0.84	ND	$0.84 \pm 0.01$	$1.460 \pm 0.010$
crotonaldehyde	4170-30-0	0.12	0.03	$0.09 \pm 0.00$	$0.153 \pm 0.004$
butyraldehyde	123-72-8	0.80	ND	$0.80 \pm 0.05$	$1.394 \pm 0.081$
benzaldehyde	100-52-7	0.35	ND	$0.35 \pm 0.01$	$0.608 \pm 0.019$
isovaleraldehyde	590-86-3	ND	ND	ND	ND
valeraldehyde	110-62-3	0.17	ND	$0.17 \pm 0.02$	$0.298 \pm 0.029$
<i>o</i> -tolualdehyde	529-20-4	ND	ND	ND	ND
<i>m</i> -tolualdehyde	620-23-5	0.14	ND	$0.14 \pm 0.00$	$0.251 \pm 0.003$
<i>p</i> -tolualdehyde	104-87-0	ND	ND	ND	ND
hexaldehyde	66-25-1	0.13	0.02	$0.11 \pm 0.01$	$0.191 \pm 0.018$
2,5-dimethylbenzaldehyde	5779-94-2	ND	ND	ND	ND
diacetyl	431-03-8	ND	ND	ND	ND
methacrolein	78-85-3	0.36	ND	$0.36 \pm 0.02$	$0.627 \pm 0.037$
2-butanone	78-93-3	0.54	0.01	$0.53 \pm 0.04$	$0.917 \pm 0.075$
glyoxal	107-22-2	1.80	ND	$1.80 \pm 0.05$	$3.133 \pm 0.086$
acetophenone	98-86-2	0.91	ND	$0.91 \pm 0.04$	$1.572 \pm 0.075$
methylglyoxal	78-98-8	0.55	ND	$0.55 \pm 0.07$	$0.960 \pm 0.118$
octanal	124-13-0	ND	ND	ND	ND
nonanal	124-19-6	0.58	0.07	$0.51 \pm 0.04$	$0.891 \pm 0.072$
Total Speciated		53.45	0.36	53.09	
Total Unspeciated		6.90	2.33	4.57	
Total Speciated + Unspeciated		60.35	2.69	57.66	
Mass emission rate of Speciated Carbonyls = 2.53 mg/kg fuel					
Mass emission rate of Total Carbonyls (Speciated + Unspeciated) = 2.74 mg/kg fuel					

<sup>a</sup> Percent of each compound expressed as a percentage of Total Speciated + Unspeciated carbonyl compounds.

<sup>b</sup> ND = Compound not detected.

**Table 5-3b. Carbonyl Compounds Analyzed by High Performance Liquid Chromatography Field Samples, August 9, 2000**

Compound	CAS No.	Res. Chamber Pair μ g	Blank μ g	Corrected Value	% Total <sup>a</sup>
formaldehyde	50-00-0	12.29	0.04	12.26 ± 1.35	47.603 ± 5.246
acetaldehyde	75-07-0	2.64	0.08	2.56 ± 0.03	9.930 ± 0.113
acetone	67-64-1	0.77	0.22	0.55 ± 0.02	2.118 ± 0.090
propionaldehyde	123-38-6	0.43	ND <sup>b</sup>	0.43 ± 0.00	1.662 ± 0.011
crotonaldehyde	4170-30-0	0.07	ND	0.07 ± 0.00	0.264 ± 0.007
butyraldehyde	123-72-8	0.59	0.09	0.51 ± 0.03	1.961 ± 0.115
benzaldehyde	100-52-7	0.20	0.02	0.18 ± 0.01	0.705 ± 0.022
isovaleraldehyde	590-86-3	ND	ND	ND	ND
valeraldehyde	110-62-3	0.07	ND	0.07 ± 0.01	0.280 ± 0.27
<i>o</i> -tolualdehyde	529-20-4	ND	ND	ND	ND
<i>m</i> -tolualdehyde	620-23-5	0.10	0.03	0.07 ± 0.00	0.276 ± 0.004
<i>p</i> -tolualdehyde	104-87-0	0.04	ND	0.04 ± 0.00	0.157 ± 0.009
hexaldehyde	66-25-1	0.07	0.02	0.05 ± 0.00	0.198 ± 0.018
2,5-dimethylbenzaldehyde	5779-94-2	ND	ND	ND	ND
diacetyl	431-03-8	ND	ND	ND	ND
methacrolein	78-85-3	0.19	ND	0.19 ± 0.01	0.718 ± 0.042
2-butanone	78-93-3	0.21	0.03	0.18 ± 0.01	0.703 ± 0.057
glyoxal	107-22-2	2.06	ND	2.06 ± 0.06	8.000 ± 0.218
acetophenone	98-86-2	0.24	ND	0.24 ± 0.01	0.924 ± 0.044
methylglyoxal	78-98-8	0.55	ND	0.55 ± 0.07	2.120 ± 0.260
octanal	124-13-0	ND	ND	ND	ND
nonanal	124-19-6	0.48	ND	0.48 ± 0.04	1.868 ± 0.151
Total Speciated		21.99	0.52	21.47	
Total Unspeciated		6.13	1.48	4.65	
Total Speciated + Unspeciated		27.12	2.00	25.12	
Mass emission rate of Speciated Carbonyls = 0.80 mg/kg fuel					
Mass emission rate of Total Carbonyls (Speciated + Unspeciated) = 0.94 mg/kg fuel					

<sup>a</sup> Percent of each compound expressed as a percentage of Total Speciated + Unspeciated carbonyl compounds.

<sup>b</sup> ND = Compound not detected.

The mass emission rates of speciated plus unspeciated carbonyl compounds for the second testing day (8/9/2000) was approximately half the value observed on the first testing day. On a compound-by-compound basis, values for Day 1 are generally higher than values for Day 2, with the lighter carbonyl compounds (formaldehyde, acetaldehyde, and acetone) a factor of 2 to 3 higher on the first day than on the second day. There is no obvious explanation for these results based on the process information or testing conditions.

The values for total mass of carbonyl compounds (speciated and speciated + unspeciated corrected for the blank values) are shown in Table 5-4.

**Table 5-4. Total Mass of Carbonyl Compounds for Each Test Day: Speciated and (Speciated + Unspeciated), Corrected for Blanks**

Sample	Total Mass, $\mu\text{g}$	
	Speciated	Speciated + Unspeciated
Cartridge Pair (8/8/00)	53.45	60.35
Blank (8/8/00)	0.36	2.69
Corrected Value	53.09	57.66
Cartridge Pair (8/9/00)	21.99	27.12
Blank (8/9/00)	0.52	2.00
Corrected Value	21.47	25.12

These values were used in combination with the flow information and the mass of fuel consumed to calculate a mass emission rate of carbonyl compounds for each testing day; these calculations are shown in Tables G-3 through G-6.

The mass emission rates for speciated carbonyl compounds for the two test days were 2.53 mg/kg of fuel (Day #1) and 0.80 mg/kg of fuel (Day #2). The mass emission rates for all carbonyl compounds (speciated + unspeciated) for the two test days were 2.74 mg/kg of fuel (Day #1) and 0.94 mg/kg of fuel (Day #2). These mass emission rates reflect the difference in total mass of carbonyl compounds observed between the two days (a factor of more than two),

rather than a difference in the mass of fuel consumed (97,690 vs. 127,027 kg), since slightly more fuel was actually consumed on Testing Day 2.

### **Gas-Phase Air Toxics Whole Air Samples**

Analytical results for the air toxics canister samples are shown in Table 5-5. The ERG concurrent analysis produces analytical results for both air toxics and nonmethane organic compound ozone precursors; these results are presented separately.

Method Detection Limits for the Air Toxics analysis are shown in Table 4-9, with values typically ranging to  $1 \mu\text{g}/\text{m}^3$  and lower. These values are at the lower end of the calibration curve for this analysis, and the typical ambient levels observed for these analytes show a maximum of  $20 \mu\text{g}/\text{m}^3$  where the compounds are observed at detectable levels. Relative to the analytical scale for ambient analysis, some very high values are observed for propylene, methylene chloride, and benzene. For propylene and methylene chloride, the concentrations obtained for the Dilution Air are approximately the same as the values obtained for the Residence Chamber Air, indicating that the compounds are present in the ambient air at the source. In the case of benzene, however, the concentration determined for the Residence Chamber Air is nearly three orders of magnitude higher than the concentration observed in the Dilution Air, indicating that the compound is present in the source at relatively high levels compared to ambient standards.

### **Gas-Phase Speciated Nonmethane Organic Compounds**

Analysis of whole air samples of Dilution Air and Residence Chamber Air using ERG's concurrent analysis generated analytical data for Speciated Nonmethane Organic Compounds (SNMOC), shown in Tables 5-6(a, b). Analytical results are presented in weight percent of total SNMOC (speciated + unspeciated). Mass emission rates of total SNMOC and total speciated plus unspeciated organic compounds are also provided. A Blank canister is a canister that has had no exposure to the stationary source matrix. Samples labeled "Dilution Air" reflect the

**Table 5-5. Analytical Results for Field Samples, Air Toxics Compounds (Analytical Method TO-15)**

Compound	CAS No.	Blank	Dilution	Residence	Blank	Dilution	Residence
		8/8/00	Air	Chamber Air	8/9/00	Air	Chamber Air
		$\mu\text{g}/\text{m}^3$			$\mu\text{g}/\text{m}^3$		
acetylene	74-86-2	ND	0.76	1.26	ND	0.68	7.19
propylene	115-07-1	ND	59.4	54.34	ND	7.2	10.4
dichlorodifluoromethane	75-71-8	ND	24.85	30.88	ND	128	130
chloromethane	74-87-3	ND	2.24	1.04	ND	1.39	1.33
dichlorotetrafluoroethane	1320-37-2	ND	ND	ND	ND	ND	ND
vinyl chloride	75-01-4	ND	ND	ND	ND	ND	ND
1,3-butadiene	106-99-0	ND	ND	ND	ND	ND	ND
bromomethane	74-83-9	ND	ND	ND	ND	ND	ND
chloroethane	75-00-3	ND	ND	ND	ND	ND	ND
acetonitrile	75-05-8	ND	ND	9.94	ND	10.50	15.55
acetone	67-64-1	ND	ND	ND	ND	ND	ND
trichlorofluoromethane	75-69-4	ND	ND	ND	ND	ND	ND
acrylonitrile	107-13-1	ND	ND	ND	ND	ND	ND
1,1-dichloroethene	75-35-4	ND	ND	ND	ND	ND	ND
methylene chloride	75-09-2	ND	77.87	47.99	ND	8.43	7.53
trichlorotrifluoroethane	26523-64-8	ND	ND	ND	ND	ND	ND
<i>trans</i> -1,2-dichloroethylene	56-60-5	ND	ND	ND	ND	ND	ND
1,1-dichloroethane	75-34-3	ND	ND	ND	ND	ND	ND
methyl <i>tert</i> -butyl ether	1634-04-1	ND	ND	ND	ND	ND	ND
methyl ethyl ketone	78-93-3	ND	ND	23.05	ND	3.62	16.43
chloroprene	126-99-8	ND	ND	ND	ND	ND	ND

(Continued)



Table 5-5. (Continued)

		Residence			Residence		
		Blank	Dilution	Chamber	Blank	Dilution	Chamber
		8/8/00	Air	Air	8/9/00	Air	Air
Compound	CAS No.	µg/m³			µg/m³		
cis-1,3-dichloroethylene	156-59-2	ND	ND	ND	ND	ND	ND
bromochloromethane	74-97-5	ND	ND	ND	ND	ND	ND
chloroform	67-66-3	ND	ND	ND	ND	ND	ND
ethyl tert-butyl ether	637-92-3	ND	ND	ND	ND	ND	ND
1,2-dichloroethane	107-06-2	ND	ND	ND	ND	ND	ND
1,1,1-trichloroethane	71-55-6	ND	ND	ND	ND	ND	ND
benzene	71-43-2	ND	0.51	420	ND	0.45	108.50
carbon tetrachloride	56-23-5	ND	ND	ND	ND	ND	ND
tert-amyl methyl ether	994-05-8	ND	ND	ND	ND	ND	ND
1,2-dichloropropane	78-87-5	ND	ND	ND	ND	ND	ND
ethyl acrylate	140-88-5	ND	ND	ND	ND	ND	ND
bromodichloro-methane	75-27-4	ND	ND	ND	ND	ND	ND
trichloroethylene	79-01-6	ND	ND	10.70	ND	ND	ND
methyl methacrylate	80-62-6	ND	ND	ND	ND	ND	ND
cis-1,2-dichloropropene	10061-01-5	ND	ND	ND	ND	ND	ND
methyl isobutyl ketone	108-10-1	ND	9.56	ND	ND	ND	ND
trans-1,2-dichloropropene	10061-02-6	ND	ND	ND	ND	ND	ND
1,1,2-trichloroethane	79-00-5	ND	ND	ND	ND	ND	ND
toluene	108-88-3	ND	1.13	3.95	ND	0.68	1.88
dibromochloromethane	124-48-1	ND	ND	ND	ND	ND	ND
1,2-dibromoethane	106-93-4	ND	ND	ND	ND	ND	ND

(Continued)

Table 5-5. (Continued)

Compound	CAS No.	Blank	Dilution	Residence	Blank	Dilution	Residence
		8/8/00	Air	Chamber	8/9/00	Air	Chamber
			µg/m <sup>3</sup>	Air		µg/m <sup>3</sup>	
<i>n</i> -octane	111-65-9	ND	1.95	2.33	ND	0.65	ND
tetrachloroethylene	127-18-4	ND	ND	ND	ND	ND	1.40
chlorobenzene	108-90-7	ND	ND	ND	ND	ND	ND
ethylbenzene	100-41-4	ND	ND	1.13	ND	1.21	ND
<i>m</i> -, <i>p</i> -xylene	108-38-3/106-42-3	ND	0.52	2.94	ND	8.13	7.09
bromoform	75-25-2	ND	ND	ND	ND	ND	ND
styrene	100-42-5	ND	0.34	0.76	ND	0.72	0.76
1,1,2,2-tetrachloroethane	79-34-5	ND	ND	ND	ND	ND	ND
<i>o</i> -xylene	95-47-6	ND	ND	0.65	ND	0.91	0.91
1,3,5-trimethylbenzene	108-67-8	ND	ND	ND	ND	ND	ND
1,2,4-trimethylbenzene	95-63-6	ND	0.69	0.74	ND	0.64	0.64
<i>m</i> -dichlorobenzene	541-73-1	ND	ND	ND	ND	ND	ND
chloromethylbenzene	100-44-7	ND	ND	ND	ND	ND	ND
<i>p</i> -dichlorobenzene	106-46-7	ND	ND	ND	ND	ND	ND
<i>o</i> -dichlorobenzene	95-50-1	ND	ND	ND	ND	ND	ND
1,2,4-trichlorobenzene	120-82-1	ND	ND	ND	ND	ND	ND
hexachloro-1,3-butadiene	87-68-3	ND	ND	ND	ND	ND	ND

ND = Not detected; compound not observed in the performance of the analysis.

**Table 5-6a. Speciated Nonmethane Organic Compound Data, August 8, 2000**

	Compound	CAS No.	Total µg Res. Cham.	Total µg Dilution	Total µg	% Total Speciated + Unspeciated
∞	ethylene	4-84-0	3180.83	349.96	2830.87 ± 276.29	0.020 ± 0.200
	acetylene	74-86-2	2035.38	184.52	1850.86 ± 180.64	0.013 ± 0.131
	ethane	74-85-1	1507.05	585.39	921.66 ± 109.59	0.007 ± 0.079
	propylene	115-07-01	11549.73	12140.43	*	0.00
	propane	74-98-6	10482.23	11022.68	*	0.00
	propyne	74-99-7	ND	ND	ND	0.00
	isobutane	75-28-5	326.96	144.23	182.73 ± 6.7	0.001 ± 0.005
	isobutene/1-butene	115-11-7/106-98-0	513.18	184.52	328.65 ± 10.94	0.002 ± 0.008
	1,3-butadiene	106-99-0	67.12	ND	67.12 ± 2.3	0.000 ± 0.002
	<i>n</i> -butane	106-97-8	337.79	180.28	157.50 ± 5.54	0.001 ± 0.004
	<i>trans</i> -2-butene	624-64-6	121.26	48.78	72.47 ± 2.82	0.000 ± 0.002
	<i>cis</i> -2-butene	590-18-1	145.08	91.20	53.87 ± 1.85	0.000 ± 0.001
	3-methyl-1-butene	563-45-1	28.15	ND	28.15 ± 0.89	0.000 ± 0.001
	isopentane	78-78-4	132.08	112.41	19.67 ± 0.57	0.000 ± 0.000
	1-pentene	109-67-1	ND	ND	ND	0.00
	2-methyl-1-butene	563-46-2	34.64	ND	34.64 ± 0.99	0.000 ± 0.001
	<i>n</i> -pentane	109-66-0	181.89	53.02	128.86 ± 3.57	0.001 ± 0.003
	isoprene	78-79-4	99.60	892.93	*	0.00
	<i>trans</i> -2-pentene	646-04-8	132.08	63.63	68.45 ± 2.07	0.000 ± 0.002
	<i>cis</i> -2-pentene	627-20-3	110.43	76.35	34.08 ± 1.07	0.000 ± 0.001
	2-methyl-2-butene	513-35-9	ND	ND	ND	0.00
	2,2-dimethylbutane	75-83-2	1180.09	2104.00	*	0.00

(Continued)

**Table 5-6a. (Continued)**

	Compound	CAS No.	Total µg Res. Cham.	Total µg Dilution	Total µg	% Total Speciated + Unspeciated
68	cyclopentene	142-29-0	49.80	46.66	3.14 ± 0.10	2.27E-05 ± 0.000
	4-methyl-1-pentene	691-37-2	ND	ND	ND	0.00
	cyclopentane	287-92-3	86.61	78.48	8.14 ± 0.27	5.89E-05 ± 0.000
	2,3-dimethylbutane	79-29-8	129.72	125.14	4.78 ± 0.15	3.46E-05 ± 0.000
	2-methylpentane	107-83-5	ND	114.53	*	0.00
	3-methylpentane	96-14-0	108.27	114.53	*	0.00
	2-methyl-1-pentene	763-29-1	ND	ND	ND	0.00
	1-hexene	592-41-6	342.12	144.23	197.89 ± 6.47	0.001 ± 0.005
	2-ethyl-1-butene	760-21-4	ND	ND	ND	0.00
	<i>n</i> -hexane	110-54-3	472.04	1351.06	*	0.00
	<i>trans</i> -2-hexene	4050-45-7	ND	ND	ND	0.00
	<i>cis</i> -2-hexene	7688-21-3	ND	ND	ND	0.00
	methylcyclopentane	96-37-7	140.74	184.52	*	0.00
	2,4-dimethylpentane	108-08-7	88.78	78.48	10.30 ± 0.26	7.45E-05 ± 0.000
	benzene	71-43-2	86655.43	74.23	86581.19 ± 2155.87	0.626 ± 1.560
	cyclohexane	110-82-7	97.44	84.84	12.60 ± 0.33	9.12E-05 ± 0.000
	2-methylhexne	591-76-4	47.64	195.13	*	0.00
	2,3-dimethylpentane	565-59-3	99.60	112.41	*	0.00
	3-methylhexane	589-34-4	207.87	241.79	*	0.00
	1-heptene	592-76-7	ND	31.81	*	0.00
	2,2,4-trimethylpentane	540-84-1	ND	129..38	*	0.00
	<i>n</i> -heptane	142-82-5	326.96	142.11	184.86 ± 4.10	0.001 ± 0.003

(Continued)

Table 5-6a. (Continued)

Compound	CAS No.	Total µg Res. Cham.	Total µg Dilution	Total µg	% Total Speciated + Unspeciated
methylcyclohexane	108-87-2	173.22	1679.81	*	0.00
2,2,3-trimethylpentane	564-02-3	ND	ND	ND	0.00
2,3,4-trimethylpentane	565-75-3	108.27	76.35	31.91 ± 0.75	0.000 ± 0.001
toluene	108-88-3	844.47	277.85	566.62 ± 8.67	0.004 ± 0.006
2-methylheptane	592-27-8	90.94	93.32	*	0.00
3-methylheptane	589-81-1	140.74	118.77	21.97 ± 0.50	0.000 ± 0.000
1-octene	111-66-0	179.72	55.15	124.57 ± 3.38	0.001 ± 0.002
<i>n</i> -octane	111-65-9	588.96	506.91	82.05 ± 2.58	0.001 ± 0.002
ethylbenzene	100-41-4	294.48	214.22	80.26 ± 3.23	0.001 ± 0.002
<i>m</i> -xylene/ <i>p</i> -xylene	108-38-3/106-42-3	368.10	256.64	111.46 ± 4.60	0.001 ± 0.003
styrene	100-42-5	162.40	142.11	20.29 ± 0.45	0.000 ± 0.000
<i>o</i> -xylene	95-47-6	ND	133.62	*	0.00
1-nonene	124-11-8	69.29	27.57	41.72 ± 1.83	0.000 ± 0.001
<i>n</i> -nonane	111-84-2	290.15	171.80	118.35 ± 5.24	0.001 ± 0.004
isopropylbenzene	98-82-8	90.94	69.99	20.95 ± 0.77	0.000 ± 0.001
alpha-pinene	80-56-8	621.44	1011.70	*	0.00
<i>n</i> -propylbenzene	103-65-1	99.60	74.23	25.37 ± 0.56	0.000 ± 0.000
<i>m</i> -ethyltoluene	620-14-4	309.64	322.39	*	0.00
<i>p</i> -ethyltoluene	622-96-8	225.19	218.46	6.73 ± 0.15	4.87E-05 ± 0.000
1,3,5-trimethylbenzene	108-67-8	242.51	214.22	28.30 ± 0.42	0.000 ± 0.000
<i>o</i> -ethyltoluene	611-14-3	558.65	545.09	13.56 ± 0.29	9.81E-05 ± 0.000
β-pinene	127-91-3	398.42	439.04	*	0.00

(Continued)

**Table 5-6a. (Continued)**

Compound	CAS No.	Total µg Res. Cham.	Total µg Dilution	Total µg	% Total Speciated + Unspeciated
1,2,4-trimethylbenzene	95-63-6	389.75	305.42	84.33 ± 0.25	0.001 ± 0.000
1-decene	872-05-9	ND	ND	ND	0.00
<i>n</i> -decane	124-18-5	6225.25	6273.83	*	0.00
1,2,3-trimethylbenzene	526-73-8	110.43	84.84	25.59 ± 0.06	0.000 ± 0.000
<i>m</i> -diethylbenzene	141-93-5	123.42	142.11	*	0.00
<i>p</i> -diethylbenzene	105-05-5	43.31	50.90	*	0.00
1-undecene	821-95-4	ND	ND	ND	0.00
<i>n</i> -undecane	1120-21-4	961.39	950.19	11.20 ± 0.86	8.1E-05 ± 0.001
1-dodecene	112-41-4	207.87	178.16	29.71 ± 0.32	0.000 ± 0.000
<i>n</i> -dodecane	112-40-3	30838.25	30278.97	559.28 ± 30.82	0.004 ± 0.022
1-tridecene	2437-56-1	225.19	173.92	51.27 ± 2.83	0.000 ± 0.002
<i>n</i> -tridecane	629-50-5	194.88	178.16	16.72 ± 0.92	0.01 ± 0.001
Total speciated		166195.67	76749.42	89446.25	
Total unspeciated		65119.32	16335.71	48783.61	
Total speciated + unspeciated**		231314.99	93085.13	138229.9	
Mass emission rate of Total Speciated NMOC = 13.191 mg/kg fuel					
Mass emission rate of Speciated + Unspeciated NMOC = 22.640 mg/kg fuel					

ND = Compound not detected.

\*Concentration of analyte in Dilution Air is higher than concentration of analyte in Residence Chamber Air when dilution factor of 48.8 is considered.

\*\*Total NMOC with unknowns in µg/m<sup>3</sup> is an estimate based on propane only.

**Table 5-6b. Speciated Nonmethane Organic Compound Data, August 9, 2000**

Compound	CAS No.	Total µg Res. Cham.	Total µg Dilution	Total µg	% Total Speciated + Unspeciated
ethylene	4-84-0	1466.12	379.08	1087.04 ± 106.10	1.386 ± 0.135
acetylene	74-86-2	2321.61	216.19	2105.42 ± 205.49	2.685 ± 0.262
ethane	74-85-1	1239.40	758.16	481.24 ± 57.22	0.614 ± 0.073
propylene	115-07-01	3028.98	2132.33	896.64 ± 27.35	1.143 ± 0.035
propane	74-98-6	7847.53	7703.05	144.47 ± 3.55	0.184 ± 0.005
propyne	74-99-7	ND	ND	ND	0.00
isobutane	75-28-5	250.90	177.69	73.21 ± 2.69	0.093 ± 0.003
isobutene/1-butene	115-11-7/106-98-0	314.38	154.00	160.38 ± 5.34	0.205 ± 0.007
1,3-butadiene	106-99-0	33.25	ND	33.25 ± 1.14	0.042 ± 0.002
<i>n</i> -butane	106-97-8	296.25	242.85	53.40 ± 1.88	0.068 ± 0.002
<i>trans</i> -2-butene	624-64-6	ND	79.96	*	0.00
<i>cis</i> -2-butene	590-18-1	145.10	115.50	29.60 ± 1.02	0.038 ± 0.001
3-methyl-1-butene	563-45-1	ND	ND	ND	0.00
isopentane	78-78-4	151.15	142.16	8.99 ± 0.26	0.011 ± 0.000
1-pentene	109-67-1	ND	ND	ND	0.00
2-methyl-1-butene	563-46-2	ND	ND	ND	0.00
<i>n</i> -pentane	109-66-0	284.16	148.08	136.08 ± 3.77	0.174 ± 0.005
isoprene	78-79-4	120.92	420.54	*	0.00
<i>trans</i> -2-pentene	646-04-8	105.80	77.00	28.80 ± 0.87	0.037 ± 0.001
<i>cis</i> -2-pentene	627-20-3	123.94	103.66	20.285 ± 0.64	0.026 ± 0.001
2-methyl-2-butene	513-35-9	ND	ND	ND	0.00
2,2-dimethylbutane	75-83-2	326.48	296.16	30.32 ± 0.98	0.039 ± 0.001

(Continued)

Table 5-6b. (Continue)

Compound	CAS No.	Total µg Res. Cham.	Total µg Dilution	Total µg	% Total Speciated + Unspeciated
cyclopentene	142-29-0	48.37	26.65	21.71 ± 0.71	0.028 ± 0.001
4-methyl-1-pentene	691-37-2	ND	ND	ND	0.00
cyclopentane	287-92-3	120.92	100.69	20.22 ± 0.67	0.026 ± 0.001
2,3-dimethylbutane	79-29-8	163.24	156.96	6.27 ± 0.19	0.008 ± 0.000
2-methylpentane	107-83-5	ND	130.31	*	0.00
3-methylpentane	96-14-0	157.19	171.77	*	0.00
2-methyl-1-pentene	763-29-1	ND	ND	ND	0.00
1-hexene	592-41-6	256.95	192.50	64.45 ± 2.11	0.082 ± 0.003
2-ethyl-1-butene	760-21-4	ND	ND	ND	0.00
<i>n</i> -hexane	110-54-3	2224.88	2615.07	*	0.00
<i>trans</i> -2-hexene	4050-45-7	ND	ND	ND	0.00
<i>cis</i> -2-hexene	7688-21-3	ND	ND	ND	0.00
methylcyclopentane	96-37-7	308641.15	349.47	308291.7 ± 9002.12	393.143 ± 11.480
2,4-dimethylpentane	108-08-7	108.83	103.66	5.17 ± 0.13	0.007 ± 0.000
benzene	71-43-2	30365.33	142.16	30223.18 ± 752.56	38.541 ± 0.960
cyclohexane	110-82-7	126.96	133.27	*	0.00
2-methylhexane	591-76-4	169.28	195.46	*	0.00
2,3-dimethylpentane	565-59-3	157.19	156.96	0.23 ± 0.02	0.000 ± 0.000
3-methylhexane	589-34-4	154.17	142.16	12.01 ± 0.29	0.015 ± 0.000
1-heptene	592-76-7	ND	35.54	*	0.00
2,2,4-trimethylpentane	540-84-1	ND	112.54	*	0.00

(Continued)



Table 5-6b. (Continue)

Compound	CAS No.	Total µg Res. Cham.	Total µg Dilution	Total µg	% Total Speciated + Unspeciated
<i>n</i> -heptane	142-82-5	136.03	103.66	32.38 ± 0.72	0.041 ± 0.001
methylcyclohexane	108-87-2	193.47	216.19	*	0.00
2,2,3-trimethylpentane	564-02-3	ND	35.54	*	0.00
2,3,4-trimethylpentane	565-75-3	102.78	91.81	10.97 ± 0.26	0.014 ± 0.000
toluene	108-88-3	580.40	308.00	272.40 ± 4.17	0.347 ± 0.005
2-methylheptane	592-27-8	139.05	130.31	8.75 ± 0.18	0.011 ± 0.000
3-methylheptane	589-81-1	108.83	94.77	14.06 ± 0.32	0.018 ± 0.000
1-octene	111-66-0	81.62	62.19	19.43 ± 0.53	0.025 ± 0.001
<i>n</i> -octane	111-65-9	396.00	432.39	*	0.00
ethylbenzene	100-41-4	414.14	414.62	*	0.00
<i>m</i> -xylene/ <i>p</i> -xylene	108-38-3/106-42-3	997.57	1128.36	*	0.00
styrene	100-42-5	287.18	331.70	*	0.00
<i>o</i> -xylene	95-47-6	ND	358.35	*	0.00
1-nonene	124-11-8	ND	ND	ND	0.00
<i>n</i> -nonane	111-84-2	296.25	281.35	14.90 ± 0.66	0.019 ± 0.001
isopropylbenzene	98-82-8	99.76	94.77	4.99 ± 0.18	0.006 ± 0.000
alpha-pinene	80-56-8	302.29	121.42	180.87 ± 5.34	0.231 ± 0.007
<i>n</i> -propylbenzene	103-65-1	108.83	142.16	*	0.00
<i>m</i> -ethyltoluene	620-14-4	601.56	568.62	32.94 ± 0.51	0.042 ± 0.001
<i>p</i> -ethyltoluene	622-96-8	314.38	313.93	0.46 ± 0.01	0.001 ± 0.000
1,3,5-trimethylbenzene	108-67-8	256.95	299.12	*	0.00

(Continued)

**Table 5-6b. (Continue)**

Compound	CAS No.	Total µg Res. Cham.	Total µg Dilution	Total µg	% Total Speciated + Unspeciated
<i>o</i> -ethyltoluene	611-14-3	556.22	518.28	37.94 ± 0.81	0.048 ± 0.001
β-pinene	127-91-3	332.52	319.85	12.67 ± 0.15	0.016 ± 0.000
1,2,4-trimethylbenzene	95-63-6	377.87	331.70	46.17 ± 0.14	0.059 ± 0.000
1-decene	872-05-9	ND	ND	ND	0.00
<i>n</i> -decane	124-18-5	7285.26	7842.25	*	0.00
1,2,3-trimethylbenzene	526-73-8	157.19	207.31	*	0.00
<i>m</i> -diethylbenzene	141-93-5	172.31	180.66	*	0.00
<i>p</i> -diethylbenzene	105-05-5	69.53	68.12	1.41 ± 0.05	0.002 ± 0.000
1-undecene	821-95-4	ND	ND	ND	0.00
<i>n</i> -undecane	1120-21-4	1091.28	1187.59	*	0.00
1-dodecene	112-41-4	287.18	284.31	2.87 ± 0.03	0.004 ± 0.000
<i>n</i> -dodecane	112-40-3	37647.57	42776.98	*	0.00
1-tridecene	2437-56-1	ND	233.96	*	0.00
<i>n</i> -tridecane	629-50-5	145.10	222.12	*	0.00
Total speciated		105995.22	55584.26	50410.96	
Total unspeciated		38326.93	10320.64	28006.29	
Total speciated + unspeciated**		144322.14	65904.90	78417.24	

ND = Compound not detected.

\*Concentration of analyte in Dilution Air is higher than concentration of analyte in Residence Chamber Air when dilution factor of 49.3 is considered.

\*\*Total NMOC with unknowns in µg/m<sup>3</sup> is an estimate based on propane only.

dilution air entering the sample dilution system; this dilution air has not been exposed to the stationary source matrix. The second canister sample on each test day is labeled “Residence Chamber Air” and reflects the diluted source matrix at the end of the residence chamber. Supporting data for the SNMOC analysis are found in Appendix H.

The Total Mass of Speciated Nonmethane Organic Compound results and the Total Speciated + Unspeciated results have been used to calculate the mass emission rates for Speciated Nonmethane Organic Compounds as well as Speciated + Unspeciated Nonmethane Organic Compounds (Table 5-7). Samples taken from the residence chamber were corrected for the SNMOC observed in the dilution air to determine the total SNMOC collected. These values were used to calculate a mass emission rate for Speciated Nonmethane Organic Compounds for each test day; these calculations are shown in Tables H-3 through H-6 (Appendix H).

**Table 5-7. Total Mass of Speciated as well as Speciated + Unspeciated Nonmethane Organic Compounds Collected, Test #1 and Test #2**

Sample	Total Mass ( $\mu\text{g}$ )	
	Total Speciated NMOC	Total Speciated + Unspeciated NMOC
Residence Chamber Air (8/8/00)	3.52	4.60
Dilution Air (8/8/00)	1.66	1.79
Corrected Value (8/8/00)	1.86	2.82
Residence Chamber Air (8/9/00)	1.93	2.50
Dilution Air (8/9/00)	1.44	1.56
Corrected Value (8/9/00)	0.49	0.93

The mass emission rate for the SNMOC is consistent with the mass emission rate observed for the carbonyl compounds: Speciated, 13,190  $\mu\text{g}/\text{kg}$  of fuel for Test Day #1 versus 50,411  $\mu\text{g}/\text{kg}$  of fuel for Test Day #2; Speciated + Unspeciated, 22,640  $\mu\text{g}/\text{kg}$  of fuel for Test

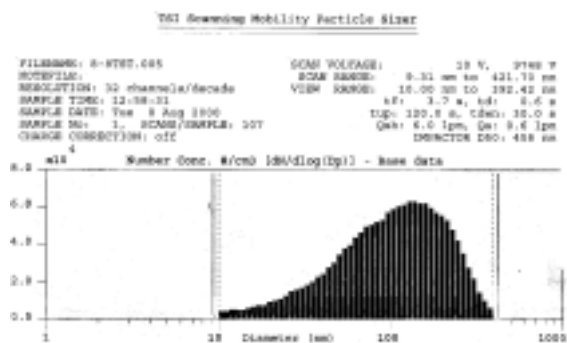
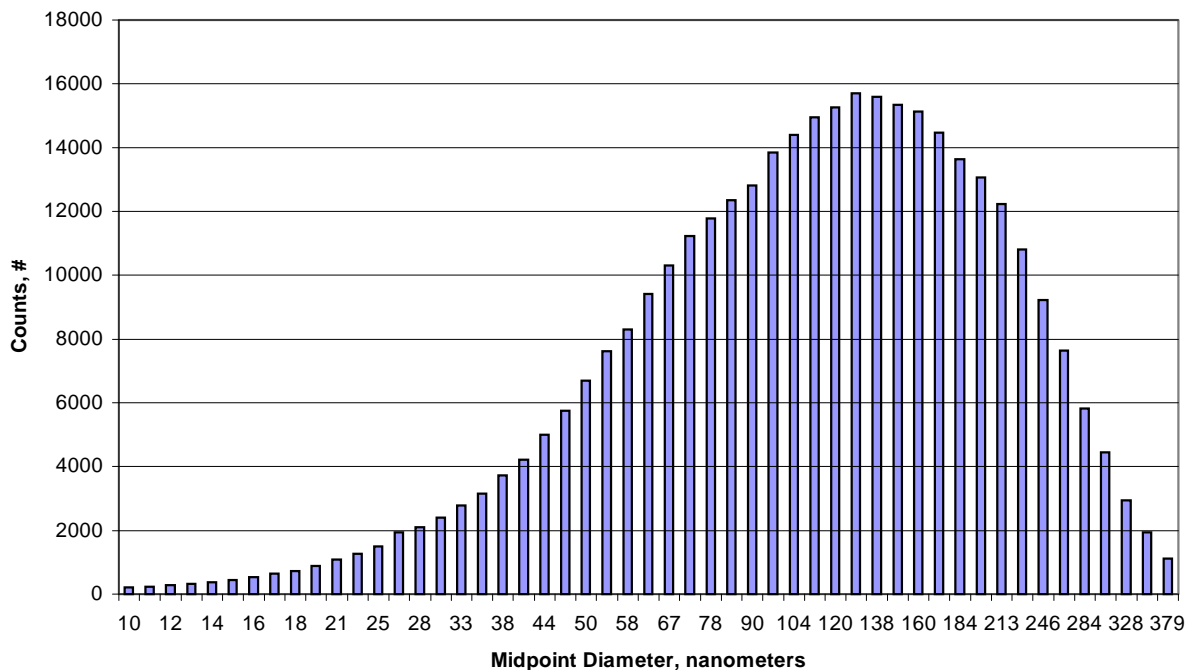
Day #1 versus 78,417  $\mu\text{g/kg}$  of fuel for Test Day #2. There is no obvious explanation for a difference of approximately a factor of two between the two test days.

### **Particle Size Distribution Data**

The TSI system was operated on both test days, collecting data on particle size distribution in the range below  $2.5\ \mu\text{m}$  (range monitored was 9 nm to approximately 400 nm). The analytical data are presented graphically as a plot of midpoint diameter of the particles vs. counts (an indirect version of number of particles in each size range) or as midpoint diameter in nanometers vs. number of particles (Figures 5-1 and 5-2). The supporting data for these plots are included in Appendix I.

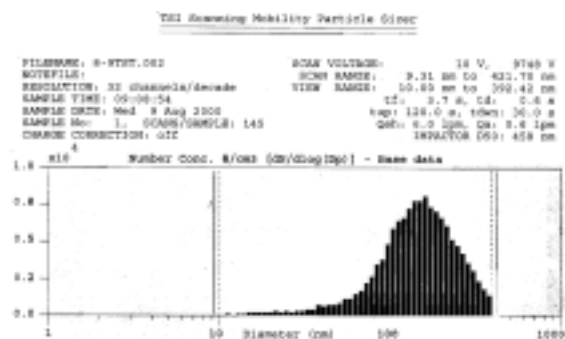
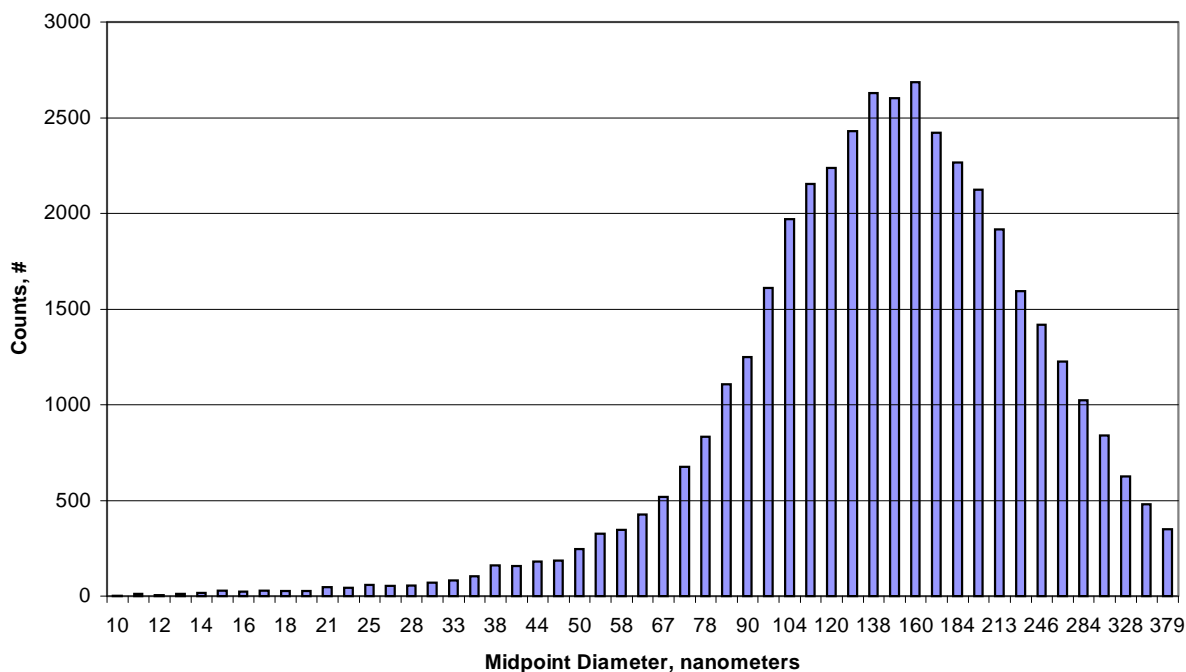
The profiles for the two days are qualitatively different. Figure 5-2 shows an obvious deficit in particles in the range of 25 through 104 nm, with a slight shift of the particle size distribution for Day 2 toward larger diameter particles. Results for particles in this size range also reflect the general difference observed in carbonyls and SNMOC between Day 1 and Day 2: a maximum of  $\sim 6 \times 10^4$  particles/ $\text{cm}^3$  for Day 1 versus  $\sim 0.8 \times 10^4$  particles/ $\text{cm}^3$  for Day 2.

8-8-00



**Figure 5-1. Particle size distribution (9 to 400 nanometers) for test day 1 (8/8/00).**  
 (Figures shown are a composite of all three-minute scans collected for the duration of the test.)

8-9-00



**Figure 5-2. Particle size distribution (9 to 400 nanometers) for test day 2 (8/9/00).**  
(Figures shown are a composite of all three-minute scans collected for the duration of the test.)

## **Section 6**

### **Quality Assurance/Quality Control**

In field sampling with the dilution sampling system, the following quality control procedures were implemented:

- A leak check of the dilution sampling system was performed before field testing was initiated;
- Pitot tubes and meter boxes were calibrated;
- The analytical balance(s) were calibrated;
- Flow control collection devices for the canisters were calibrated using a primary flow standard;
- Multipart forms recording field conditions and observations were used for canisters and carbonyl samples; and
- Strict chain of custody documentation for all field samples was maintained.

Field sampling equipment quality control requirements that were met in the course of preparing for the field test and execution of testing activities are summarized in Table 6-1.

Strict chain of custody procedures were followed in collecting and transporting samples and sampling media to and from the field sampling location. Sample substrates (filters, denuders, PUF canister, DNPH cartridges) were prepared in advance in accordance with the number and types of samples designated in the sampling matrix of the approved field test plan. Clean SUMMA<sup>®</sup> collection canisters and DNPH cartridges used to collect carbonyl compounds were prepared and supplied by ERG. The PUF, XAD-4<sup>®</sup>, denuder, and PM-2.5 sampling substrates were prepared and supplied by EPA. Chain of custody forms (Figure 6-1) were

**Table 6-1. Field Sampling Equipment Quality Control Measures**

<b>Equipment</b>	<b>Effect</b>	<b>Acceptance Criteria</b>	<b>Criteria Achieved?</b>
Orifice meters (volumetric gas flow calibration)	Ensures the accuracy of flow measurements for sample collection	$\pm 1\%$	Yes
Venturi meters (volumetric gas flow calibration)	Ensures the accuracy of flow measurements for sample collection	$\pm 1\%$ of reading	Yes
Flow transmitter (Heise gauge with differential pressure)	Ensures the accuracy of flow measurements for sample collection	$\pm 0.5\%$ of range	Yes
Analytical Balances	Ensures control of bias for all project weighing	Calibrated with Class S weights	Yes
Thermocouples	Ensures sampler temperature control	$\pm 1.5^{\circ}\text{C}$	Yes
Relative humidity probes	Ensures the accuracy of moisture measurements in the residence chamber	$\pm 2\%$ relative humidity	Yes
Sampling equipment leak check and calibration (before each sampling run)	Ensures accurate measurement of sample volume	1%	Yes
Sampling equipment field blanks	Ensures absence of contamination in sampling system	$< 5.0\%$ of sample values	Yes

Reference. EPA Quality Assurance Project Plan - Source Sampling for Fine Particulate Matter (U.S. EPA, 2001).



# Chain of Custody Record

Page \_\_\_\_\_ of \_\_\_\_\_

PROJECT			NO. OF CONTAINERS	ANALYSES						REMARKS	SAM ID NO. (For lab use only)	
SITE												
COLLECTED BY (Signature)												
FIELD SAMPLE I.D.	SAMPLE MATRIX	DATE/TIME										
REMARKS:										RELINQUISHED BY:	DATE	TIME
RECEIVED BY:	DATE	TIME	RELINQUISHED BY:	DATE	TIME	RECEIVED BY:	DATE	TIME	RELINQUISHED BY:	DATE	TIME	

LAB USE ONLY									
RECEIVED FOR LABORATORY BY:	DATE	TIME	AIRBILL NO.	OPENED BY	DATE	TIME	TEMP°C	SEAL #	

Figure 6-1. ERG chain of custody form.

started when the sampling media were prepared; each sample substrate was assigned a unique identification number by the laboratory supplying the substrates.

Sample identification numbers include a code to track:

- Source type;
- Test date;
- Sampler type;
- Substrate type;
- Sampler chamber (i.e., dilution chamber or residence chamber);
- Sampler port;
- Lane/leg;
- Position; and
- Holder number.

For samples to be analyzed in the EPA laboratories, whole sampling arrays were assembled by EPA, assigned a unique tracking number, and used for sample collection. Sample collection arrays were recovered in the field as a complete unit and transferred to the EPA laboratory for disassembly and analysis.

After collection, samples were transported to the analysis laboratories by ERG, with careful documentation of sample collection and chain of custody records for the samples being transported. Samples were stored in a secure area until they were transported to the laboratories performing analyses.

## **Carbonyl Compound Analysis**

Quality control criteria for the carbonyl analysis performed by ERG are shown in Table 6-2. Supporting analytical data are a part of the project file at ERG.

**Table 6-2. Carbonyl Analysis: Quality Control Criteria**

Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action	Criteria Achieved ?
HPLC Column Efficiency	Analyze second source QC sample (SSQC)	At setup and 1 per sample batch	Resolution between acetone and propionaldehyde $\geq 1.0$ Column efficiency $> 500$ plates	Eliminate dead volume, backflush, or replace column; repeat analysis	Yes
Linearity Check	Analyze 5-point calibration curve and SSQC in triplicate	At setup or when calibration check does not meet acceptance criteria	Correlation coefficient $\geq 0.999$ , relative error for each level against calibration curve $\pm 20\%$ or less Relative Error	Check integration, re-integrate or re-calibrate	Yes
			Intercept acceptance should be $\geq 10,000$ area counts/compound; correlates to 0.06 mg/mL	Check integration, re-integrate or re-calibrate	Yes
Retention time	Analyze calibration midpoint	Once per 10 samples	Acetaldehyde, Benzaldehyde, Hexaldehyde within retention time window established by determining $3\sigma$ or $\pm 2\%$ of the mean calibration and midpoint standards, whichever is greater	Check system for plug, regulate column temperature, check gradient and solvents	Yes
Calibration Check	Analyze midpoint standard	Once per 10 samples	85-115% recovery	Check integration, re-calibrate or re-prepare standard, re-analyze samples not bracketed by acceptable standard	Yes

(Continued)

**Table 6-2. (Continued)**

<b>Parameter</b>	<b>Quality Control Check</b>	<b>Frequency</b>	<b>Acceptance Criteria</b>	<b>Corrective Action</b>	<b>Criteria Achieved ?</b>
Calibration Accuracy	SSQC	Once after calibration in triplicate	85-115% recovery	Check integration; re-calibrate or re-prepare standard, re-analyze samples not bracketed by acceptable standard	Yes
	Analyze 0.1 µg/mL standard	Once after calibration in triplicate	± 25% difference		
System Blank	Analyze acetonitrile	Bracket sample batch, 1 at beginning and 1 at end	Measured concentration ≤ 5 x MDL	Locate contamination and document levels of contamination in file	Yes
Duplicate Analyses	Duplicate Samples	As collected	± 20% difference	Check integration; check instrument function; re-analyze duplicate samples	Yes
Replicate Analyses	Replicate injections	Duplicate samples only	≤ 10% RPD for concentrations greater than 1.0 µg/mL	Check integration, check instrument function, re-analyze duplicate samples	Yes
Method Spike/Method Spike Duplicate (MS/MSD)	Analyze MS/MSD	One MS/MSD per 20 samples	80-120% recovery for all compounds	Check calibration, check extraction procedures	Yes

## **Concurrent Air Toxics/Speciated Nonmethane Organic Compound Analysis**

The analytical system performing the concurrent analysis is calibrated monthly and blanked daily prior to sample analysis. A quality control standard is analyzed daily prior to sample analysis to ensure the validity of the current monthly response factor. Following the daily quality control standard analysis and prior to the sample analysis, cleaned, dried air from the canister cleaning system is humidified and then analyzed to determine the level of organic compounds present in the analytical system. Upon achieving acceptable system blank results -- less than or equal to 20 ppbC -- sample analysis begins. Ten percent of the total number of samples received are analyzed in replicate to determine the precision of analysis for the program. After the chromatography has been reviewed, the sample canister is returned to the canister cleaning laboratory to be prepared for subsequent sample collection episodes or sent to another laboratory for further analysis. Quality control procedures for the Air Toxics and SNMOC analyses are summarized in Table 6-3.

## **PM Mass Measurements, Elemental Analysis, Water-Soluble Ion Analysis, and GC/MS Analysis**

Quality control criteria for EPA analyses (PM mass, elemental analyses, ion chromatography analysis, and GC/MS analysis) are summarized in Tables 6-4 through 6-7; supporting data are included in the project file in the EPA laboratory.

**Table 6-3. Quality Control Procedures for the Concurrent Analysis for Air Toxics and SNMOC**

Quality Control Check	Frequency	Acceptance Criteria	Corrective Action	Criteria Achieved?
<b>Air Toxics Analysis</b>				
BFB Instrument Tune Check	Daily prior to calibration check	Evaluation criteria in data system software; consistent with Method TO-15	Retune mass spectrometer; clean ion source and quadrupoles	Yes
Five-point calibration bracketing the expected sample concentration	Following any major change, repair, or maintenance if daily quality control check is not acceptable. Calibration is valid for six weeks if calibration check criteria are met.	RSD of response factors $\leq 30\%$ Relative Retention Times (RRTs) for target peaks $\pm 0.06$ units from mean RRT	Repeat individual sample analysis; repeat linearity check; prepare new calibration standards and repeat analysis	Yes
Calibration check using mid-point of calibration range	Daily	Response factor $\leq 30\%$ bias from calibration curve average response factor	Repeat calibration check; repeat calibration curve	Yes
System Blank	Daily following tune check and calibration check	0.2 ppbv/analyte or MDL, whichever is greater Internal Standard (IS) area response $\pm 40\%$ and retention time $\pm 0.33$ min of most recent calibration check	Repeat analysis with new blank; check system for leaks, contamination; re-analyze blank.	Yes
Laboratory Control Standard (LCS)	Daily	Recovery limits 70% - 130% IS Retention Time $\pm 0.33$ min of most recent calibration	Repeat analysis; repeat calibration curve.	Yes
Replicate Analysis	All duplicate field samples	$<30\%$ RPD for compounds $>5 \times \text{MDL}$	Repeat sample analysis	Yes
Samples	All samples	IS RT $\pm 0.33$ min of most recent calibration	Repeat analysis	Yes

(Continued)

**Table 6-3. (Continued)**

<b>Quality Control Check</b>	<b>Frequency</b>	<b>Acceptance Criteria</b>	<b>Corrective Action</b>	<b>Criteria Achieved?</b>
<b>SNMOC Analysis</b>				
System Blank Analysis	Daily, following calibration check	20 ppbC total	Repeat analysis; check system for leaks; clean system with wet air	Yes
Multiple point calibration (minimum 5); propane bracketing the expected sample concentration range	Prior to analysis and monthly	Correlation coefficient ( $r^2$ ) $\geq 0.995$	Repeat individual sample analysis; repeat linearity check; prepare new calibration standards and repeat	Yes
Calibration check: midpoint of calibration curve spanning the carbon range (C <sub>2</sub> -C <sub>10</sub> )	Daily	Response for selected hydrocarbons spanning the carbon range within $\pm 30\%$ difference of calibration curve slope	Repeat calibration check; repeat calibration curve.	Yes
Replicate analysis	All duplicate field samples	Total NMOC within $\pm 30\%$ RSD	Repeat sample analysis	Yes

**Table 6-4. PM Mass Measurements: Quality Control Criteria**

<b>Parameter</b>	<b>Quality Control Check</b>	<b>Frequency</b>	<b>Acceptance Criteria</b>	<b>Corrective Action</b>	<b>Criteria Achieved?</b>
Deposition on Filter during Conditioning	Analyze Laboratory Filter Blank	Bracket sample batch, 1 at beginning and 1 at end	Mass within $\pm 15\text{mg}$ of previous weight	Adjust mass for deposition	Yes
Laboratory Stability	Analyze Laboratory Control Filter	Bracket sample batch, 1 at beginning and 1 at end	Mass within $\pm 15\text{mg}$ of previous weight	Adjust mass to account for laboratory difference	Yes
Balance Stability	Analyze Standard Weights	Bracket sample batch, 1 at beginning and 1 at end	Mass within $\pm 3\text{mg}$ of previous weight	Perform internal calibration of balance, perform external calibration of balance	Yes

**Table 6-5. Elemental Analysis: Quality Control Criteria**

<b>Parameter</b>	<b>Quality Control Check</b>	<b>Frequency</b>	<b>Acceptance Criteria</b>	<b>Corrective Action</b>	<b>Criteria Achieved?</b>
Performance Evaluation check	Analyze Monitor Sample	Once per month	$\leq 2\%$ change in each element from previous measurement	Recalibrate	Yes



**Table 6-6. Water-Soluble Ion Analysis: Quality Control Criteria**

<b>Parameter</b>	<b>Quality Control Check</b>	<b>Frequency</b>	<b>Acceptance Criteria</b>	<b>Corrective Action</b>	<b>Criteria Achieved?</b>
Linearity Check	Analyze 4-point calibration curve	At setup or when calibration check does not meet acceptance criteria	Correlation coefficient $\geq 0.999$	Recalibrate	Yes
System Dead Volume	Analyze water	Bracket sample batch, 1 at beginning and 1 at end	Within 5% of previous analysis	Check system temperature, eluent, and columns	Yes
Retention Time	Analyze standard	At setup	Each ion within $\pm 5\%$ of standard retention time	Check system temperature and eluent	Yes
Calibration check	Analyze one standard	Once every 4-10 samples	85-115% recovery	Recalibrate or re-prepare standard, re-analyze sample not bracketed by acceptable standard	Yes
System Blank	Analyze HPLC grade water	Bracket sample batch, 1 at beginning and 1 at end	No quantifiable ions	Re-analyze	Yes
Replicate Analyses	Replicate Injections	Each sample	$\leq 10\%$ RPD for concentrations greater than 1.0mg/L	Check instrument function, re-analyze samples	Yes

**Table 6-7. Quality Control Procedures for Gas Chromatography-Mass Spectrometry Analysis of Semivolatile Organic Compounds.**

Quality Control Check	Frequency	Acceptance Criteria	Corrective Action	Criteria Achieved?
Mass spectrometer instrument tune check	Daily prior to calibration check	Mass assignments $m/z$ = 69, 219, 502 ( $\pm 0.2$ ) Peak widths = 0.59-0.65 Relative mass abundances = 100 % (69); $\geq 30$ % (219); $\geq 1$ % (502).	Retune mass spectrometer; clean ion source	Yes
Five-point calibration bracketing the expected concentration range	Following maintenance or repair of either gas chromatograph or mass spectrometer or when daily quality control check is not acceptable	Correlation coefficient of either quadratic or linear regression $\geq 0.999$	Check integration, re-integrate or recalibrate	Yes
Calibration check using midpoint of calibration range	Daily	Compounds in a representative organic compound suite $> 80\%$ are $\pm 15\%$ of individually certified values. Values $\geq 20\%$ are not accepted.	Repeat analysis, repeat calibration curve	Yes
System Blank	As needed after system maintenance or repair	Potential analytes $\leq$ detection limit values	Repeat analysis; check system integrity. Reanalyze blank	Yes
Retention time check	Daily	Verify that select compounds are within $\pm 2\%$ of established retention time window	Check inlet and column flows and the various GC/MS temperature zones	Yes

## Section 7

### References

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**Appendix A**  
**Table of Unit Conversions**

## Unit Conversion Table

Multiply	By	To Obtain
atmospheres	101.3	kilopascals
atmospheres	29.92	inches of mercury
atmospheres	760	mm of mercury
atmospheres	33.94	feet of water
atmospheres	14.70	lb/in. <sup>2</sup> (psi)
Btu	1054	joules
Btu	$2.982 \times 10^{-4}$	kilowatt-hours
centimeters	0.3937	inches
cm/sec	1.969	ft/min
cm/sec	0.03281	ft/sec
cm/sec	0.036	km/hr
cm/sec	0.6	m/min
cm <sup>3</sup>	$3.53 \times 10^{-2}$	ft <sup>3</sup>
cm <sup>3</sup>	$10^{-3}$	liters
ft <sup>3</sup>	0.02832	m <sup>3</sup>
ft <sup>3</sup> /min	0.4720	liters per second
in. <sup>3</sup>	16.39	cm <sup>3</sup>
m <sup>3</sup>	35.31	ft <sup>3</sup>
ft	12	in.
ft	0.3048	m
ft of water	0.8826	in. mercury
grams	0.03527	ounces
inches	2.540	cm
inches of water	0.07355	inches of mercury
kg	2.20462	lb
km	3280.84	ft

<b>Multiply</b>	<b>By</b>	<b>To Obtain</b>
km	0.6214	miles
kilowatts	56.92	Btu per min.
liters	0.03531	ft <sup>3</sup>
liters	61.02	in. <sup>3</sup>
liters	10 <sup>-3</sup>	m <sup>3</sup>
liters per minute	5.855 x 10 <sup>-4</sup>	ft <sup>3</sup> per second
m	3.28084	ft
m	39.37	in.
m <sup>3</sup>	0.02832	ft <sup>3</sup>
miles	5280	feet
miles	1.6093	km
ounces	28.35	grams
pounds	453.6	grams
pounds per square inch	703.1	kg/m <sup>2</sup>
cm <sup>2</sup>	0.1550	in. <sup>2</sup>
ft <sup>2</sup>	929.0	cm <sup>2</sup>
ft <sup>2</sup>	0.09290	m <sup>2</sup>
temperature (°C + 273)	1	absolute temperature (K)
temperature (°C + 17.8)	1.8	temperature (°F)
temperature (°F + 460)	1	temperature (°Rankin)
temperature (°F-32)	5/9	temperature (°C)
watts	0.05692	Btu per min.
watts	44.26	foot-pounds per min.

**Appendix B**

**Supporting Data for PM-2.5**



**Table B-1. PM Masses from Wood-Fired Industrial Boiler,  
August 8, 2000 and August 9, 2000**

<b>Filter ID *</b>	<b>Tare Weight (g)</b>	<b>Final Weight (g)</b>	<b>PM mass (mg)</b>	<b>Comments</b>
T053100A IB080800Hr2A1610	0.162028	0.162413	0.385	
T053100G IB080800Hr2B1622	0.161328	0.161712	0.384	
T053100H IB080800Hr6A1613	0.158369	0.158772	0.403	
T053100I IB080800Hr6B1614	0.166334	0.16673	0.396	
Z041200B IB080800Hr8A1564	0.26073	0.261214	0.484	
Z041200C IB080800Hr8B1642	0.256683	0.257115	0.432	
T061300A IB080800Hd1B1618	0.166579	0.166761	0.182	very high for a "blank"
T060800D IB080900Hr2A1610	0.168993	0.167522	-1.471	hole in filter
T063000C IB080900Hr2B1622	0.162283	0.162382	0.099	
T063000D IB080900Hr6A1613	0.167419	0.169122	1.703	
T060800E IB080900Hr6B1614	0.176678	0.176805	0.127	
Z031300C IB080900Hr8A1564	0.268824	0.268992	0.168	
Z031300B IB080900Hr8B1642	0.273316	0.273477	0.161	
T063000B IB080900Hd1B1618	0.166107	0.166169	0.062	

\* ID Explanation:

First 8 digits – clean filter ID

IB – Name of test

080800 – Date of test

H – Hildemann sampler

r – Residence chamber or d – Dilution chamber

Next three digits (number, letter, number) – port, side, first filter

Last three digits – array number

**Appendix C**  
**Elemental Analyses**

**Table C-1. Elemental Analysis**

<b>Filter ID</b>	<b>T053100A</b>	<b>T053100G</b>
<b>Element</b>	<b>IB080800Hr2A1</b>	<b>IB080800Hr2B1</b>
	<b>wt% of PM mass</b>	<b>wt% of PM mass</b>
Sodium	0.15	0.21
Magnesium	0.18	0.16
Silicon	17.9	14.4
Phosphorus	0.11	0.07
Sulfur	4.0	3.4
Chloride	0.61	0.66
Potassium	11.1	10.2
Calcium	0.72	0.81

Analyzed for all elements with atomic number greater than 9. However, only elements with concentrations greater than one standard error above the detection limit are reported.

## **Appendix D**

### **Major Ions**

**Table D-1. Ion Chromatographic Analysis. Data from Wood-Fired Boiler  
(wt% of PM mass)**

<b>Filter ID</b>	<b>Z041400B</b>	<b>Z041400C</b>	<b>Z033100C</b>	<b>Z033100B</b>
	<b>IB080800Hr8A1</b>	<b>IB080800Hr8B1</b>	<b>IB080900Hr8A1</b>	<b>IB080900Hr8B1</b>
<b>Ion</b>				
Chloride	NQ	NQ	NQ	NQ
Nitrate	NQ	NQ	NQ	NQ
Sulfate	7.4	8.3	NQ	NQ
Potassium	6.4	7.2	6.0	6.6
Magnesium	ND	ND	ND	ND
Calcium	ND	ND	ND	ND

NQ – Not Quantified

ND – Not Detected

## **Appendix E**

### **Elemental Carbon / Organic Carbon**

**Table E-1. Elemental Carbon/Organic Carbon (wt% of PM Mass)**

<b>Filter ID</b>	<b>EC</b>	<b>OC</b>
Q060200C IB080800Hr4A1	3.3	76.8
Q051200U IB080900Hr4A1	2.7	92.4

**Appendix F**

**Semivolatile and Nonvolatile  
Organic Species**



**Table F-1. Semivolatile and Nonvolatile Organic Compounds – Mass Emission Rates for Composite Wood-Fired Boiler Test #1 (T1) August 8, 2000, and Test #2 (T2) August 9, 2000**

Mass of Fuel Consumed	=	224,717 kg
Total Volume of Combustion Air	=	(combustion air flow rate <sub>T1</sub> x time <sub>T1</sub> ) + (combustion air flow rate <sub>T2</sub> x time <sub>T2</sub> )
	=	[(9851 scfm x 257.9 min) + (9851.6 scfm x 359.7 min)] x 28.32 sLpm/scfm
	=	172,290,407 liters
Volume of Combustion Air Sampled	=	(Venturi flow rate <sub>T1</sub> x time <sub>T1</sub> ) + (Venturi flow rate <sub>T2</sub> x time <sub>T2</sub> )
	=	(17.19 sLpm x 257.9 min) + (17.06 sLpm x 359.7 min)
	=	10,569.8 liters
Volume of Dilution Air	=	(Critical Orifice flow rate <sub>T1</sub> x time <sub>T1</sub> ) + (Critical Orifice flow rate <sub>T2</sub> x time <sub>T2</sub> )
	=	(822.4 sLpm x 257.9 min) + (823.5 sLpm x 359.7 min)
	=	508,309 liters
Mass Flow Rate of Compound in Diluted Sample	=	(mass of compound collected) / [(sum of flow rates at sample collection units x (time <sub>T1</sub> + time <sub>T2</sub> ))]
	=	17.3 µg / [(8.835 sLpm + 8.865 sLpm) x (257.9 min + 359.7 min)]
	=	0.00158 µg/L
Mass Flow Rate of Compound in Dilution Air Sample	=	(mass of compound collected) / [(sum of flow rates at sample collection units x (time <sub>T1</sub> + time <sub>T2</sub> ))]
	=	0.24 µg / [(8.835 sLpm + 8.865 sLpm) x (257.9 min + 359.7 min)]
	=	0.0000219 µg/L
Mass Flow Rate Corrected for Compound in Dilution Air	=	(mass flow rate of compound in diluted sample) – (mass flow rate of compound in dilution air)
	=	(0.00158 µg/L) - (0.0000219 µg/L)
	=	0.00156 µg/L
Dilution Ratio	=	[(volume of dilution air <sub>T1</sub> +volume of dilution air <sub>T2</sub> ) + (volume of combustion air sampled <sub>T1</sub> + volume of combustion air sampled <sub>T2</sub> )] / (volume of combustion air sampled <sub>T1</sub> + volume of combustion air sampled <sub>T2</sub> )
	=	[(212096.96 liters + 296157 liters) + (4433.3 liters + 6135 liters)] / (4433.3 liters + 6135 liters)
	=	49.09
Mass Flow Rate of Compound in Undiluted Sample	=	(mass flow rate of compound corrected for dilution air PM) x (dilution ratio)
	=	(0.00156 µg/L) x (49.09)
	=	0.076 µg/L
Mass of Compound in Sampled Air	=	(mass flow rate of compound in undiluted sample) x (volume of combustion air sampled <sub>T1</sub> + volume of combustion air sampled <sub>T2</sub> )
	=	(0.076 µg/L) * (4433.3 liters + 6135 liters)
	=	803.19 µg
Mass of compound in total combustion air	=	[(mass of compound in sampled air) / (volume of combustion air sampled <sub>T1</sub> + volume of combustion air sampled <sub>T2</sub> )] x (total volume of combustion air <sub>T1</sub> +total volume of combustion air <sub>T2</sub> )
	=	[(803.19 µg) / (4433.3 liters + 6135 liters)] x (172,290,407 liters)
	=	13,094,057.9 µg
Mass emission rate of compound	=	(mass of compound in total combustion air) / (mass of fuel consumed)
	=	13,094,057.9 µg / 224,717 kg
	=	58.27 µg/kg fuel consumed

**Table F-2. Calculated Gas- and Particle-Phase Emissions from the Wood-Fired Boiler, August 8, 2000 and August 9, 2000**

**Denuders**

		Mass of fuel (kg)	224717
		Dilution ratio	49.05
		Total air introduced (m <sup>3</sup> )	172275.6
		Time (min)	617.55
		Flow rate (L/min)	35.24
		Extract Volume (μL)	210.00
		Extract Volume (μL)	245.00
		<b>Denuder (Composite of August 8 and August 9)</b>	
<b>Compound</b>	<b>August 8 Extract Concentration D0619001&amp;2 (ng/μL)</b>	<b>August 9 Extract Concentration D710001&amp;2 (ng/μL)</b>	<b>Compound Emission Rate (μg/kg)</b>
Naphthalene	0.15	0.58	0.30
Acenaphthylene	ND	ND	ND
Acenaphthene	ND	ND	ND
Fluorene	ND	ND	ND
Phenanthrene	ND	0.56	0.24
Anthracene	ND	ND	ND
Fluoranthene	ND	ND	ND
Pyrene	ND	ND	ND
Benzo[a]anthracene	ND	ND	ND
Chrysene	ND	ND	ND
Benzo[b]fluoranthene	ND	ND	ND
Benzo[k]fluoranthene	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND
Benzo[ghi]perylene	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND
Indeno[1,2,3-cd]fluoranthene	ND	ND	ND
Dibenzo[a,h]anthracene	ND	ND	ND
Coronene	ND	ND	ND
1-Methylnaphthalene	ND	ND	ND
2-Methylnaphthalene	ND	ND	ND
2,7-Dimethylnaphthalene	ND	ND	ND
1,3-Dimethylnaphthalene	ND	ND	ND
2,6-Dimethylnaphthalene	ND	ND	ND
9-Methylanthracene	ND	ND	ND
Methylfluorene	ND	ND	ND
bis(2-Ethylhexyl)phthalate	2.42	1.69	1.59
Butyl benzyl phthalate	12.97	7.87	8.04
Diethyl phthalate	1.28	2.33	1.45
Dimethyl phthalate	0.38	0.45	0.33
Di- <i>n</i> -butyl phthalate	1.18	0.47	0.63
Di- <i>n</i> -octyl phthalate	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

<b>Compound</b>	<b>August 8</b>	<b>August 9</b>	<b>Denuder (Composite</b>
	<b>Extract Concentration</b> <b>D0619001&amp;2</b> <b>(ng/μL)</b>	<b>Extract Concentration</b> <b>D710001&amp;2</b> <b>(ng/μL)</b>	<b>of August 8 and</b> <b>August 9)</b> <b>Compound Emission</b> <b>Rate</b> <b>(μg/kg)</b>
Octylcyclohexane	ND	ND	ND
Decylcyclohexane	ND	ND	ND
Tridecylcyclohexane	ND	ND	ND
Nonadecylcyclohexane	ND	ND	ND
Norpristane	ND	ND	ND
Pristane	ND	ND	ND
Phytane	ND	ND	ND
Squalane	ND	ND	ND
ABB-20R-C27-Cholestane	ND	ND	ND
BAA-20R-C27-Cholestane	ND	ND	ND
AAA-20S-C27-Cholestane	ND	ND	ND
AAA-20R-C27-Cholestane	ND	ND	ND
ABB-20R-C28-Methylcholestane	ND	ND	ND
ABB-20R-C29-Ethylcholestane	ND	ND	ND
17A(H)-22, 29, 30-Trisnorhopane	ND	ND	ND
17B(H)-21A(H)-30-Norhopane	ND	ND	ND
17B(H)-21B(H)-Hopane	ND	ND	ND
17B(H)-21A(H)-Hopane	ND	ND	ND
17A(H)-21B(H)-Hopane	ND	ND	ND
<i>n</i> -Decane (C10)	ND	ND	ND
<i>n</i> -Undecane (C11)	ND	ND	ND
<i>n</i> -Dodecane (C12)	3.12	6.63	3.94
<i>n</i> -Tridecane (C13)	ND	1.41	0.60
<i>n</i> -Tetradecane (C14)	2.68	4.80	3.00
<i>n</i> -Pentadecane (C15)	0.73	1.47	0.89
<i>n</i> -Hexadecane (C16)	2.13	3.05	2.06
<i>n</i> -Heptadecane (C17)	1.32	1.22	1.00
<i>n</i> -Octadecane (C18)	0.70	1.21	0.77
<i>n</i> -Nonadecane (C19)	2.90	1.69	1.77
<i>n</i> -Eicosane (C20)	15.42	ND	5.60
<i>n</i> -Heneicosane (C21)	28.04	20.75	18.96
<i>n</i> -Docosane (C22)	221.83	188.49	160.29
<i>n</i> -Tricosane (C23)	202.81	1125.95	550.25
<i>n</i> -Tetracosane (C24)	135.10	68.73	78.12
<i>n</i> -Pentacosane (C25)	49.27	35.38	32.86
<i>n</i> -Hexacosane (C26)	17.26	14.43	12.37
<i>n</i> -Heptacosane (C27)	9.81	8.99	7.37
<i>n</i> -Octacosane (C28)	8.03	7.97	6.29
<i>n</i> -Nonacosane (C29)	4.76	3.91	3.38
<i>n</i> -Triacontane (C30)	1.63	1.26	1.12

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compound	August 8	August 9	Denuder (Composite of August 8 and August 9)
	Extract Concentration D0619001&2 (ng/μL)	Extract Concentration D710001&2 (ng/μL)	Compound Emission Rate (μg/kg)
<i>n</i> -Hentriacontane (C31)	0.98	0.75	0.67
<i>n</i> -Dotriacontane (C32)	1.17	0.86	0.79
<i>n</i> -Tritriacontane (C33)	0.63	0.55	0.46
<i>n</i> -Tetratriacontane (C34)	0.49	0.28	0.30
<i>n</i> -Pentatriacontane (C35)	1.45	0.98	0.94
<i>n</i> -Hexatriacontane (C36)	ND	0.98	0.75
<i>n</i> -Tetracontane (C40)	ND	ND	ND
3-Methylnonadecane	ND	0.78	0.33
2-Methylnonadecane	2.91	1.53	1.70
Cyclopenta[cd]pyrene	ND	ND	ND
Dibenzo[a,e]pyrene	ND	ND	ND
Pyrene	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND
Methylfluoranthene	ND	ND	ND
Methylchrysene	ND	ND	ND
Retene	ND	ND	ND
Anthroquinone	ND	ND	ND
9-Fluorenone	ND	ND	ND
Benzo[a]anthracene-7,12-dione	ND	ND	ND
1,8 Naphthalic anhydride	ND	ND	ND
Squalene	2.71	3.93	2.65
1-Octadecene	3.17	ND	1.15
Benzo[e]pyrene	ND	ND	ND
Oxalic acid (C2)	ND	ND	ND
Malonic acid (C3)	ND	ND	ND
Maleic acid (C3=)	ND	ND	ND
Fumaric acid (C4=)	ND	ND	ND
Succinic acid (C4) Butanedioic acid	ND	ND	ND
Glutaric acid (C5) Pentanedioic acid	ND	ND	ND
Adipic acid (C6) Hexanedioic acid	ND	ND	ND
Pimelic acid (C7) Heptanedioic acid	ND	ND	ND
Suberic acid (C8) Octanedioic acid	ND	ND	ND
Azelaic acid (C9) Nonanedioic acid	ND	ND	ND
Sebacic acid (C10) Decanedioic acid	ND	ND	ND
Phthalic acid (1,2)	ND	7.16	3.14
Isophthalic acid (1,3)	ND	12.27	5.39
Terephthalic acid (1,4)	ND	ND	ND
1,2,4-Benzenetricarboxylic acid	ND	ND	ND
1,2,4,5-Benzenetetracarboxylic acid	ND	ND	ND
Methylphthalic acid	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

<b>Compound</b>	<b>August 8</b>	<b>August 9</b>	<b>Denuder (Composite</b>
	<b>Extract Concentration</b> <b>D0619001&amp;2</b> <b>(ng/μL)</b>	<b>Extract Concentration</b> <b>D710001&amp;2</b> <b>(ng/μL)</b>	<b>of August 8 and</b> <b>August 9)</b> <b>Compound Emission</b> <b>Rate</b> <b>(μg/kg)</b>
C6 Hexanoic acid	ND	ND	ND
C8 Octanoic acid	0.27	0.36	0.29
C9 Nonanoic acid	0.74	0.64	0.63
C10 Decanoic acid	1.08	1.17	1.02
C11 Undecanoic acid	1.11	0.39	0.69
C12 Dodecanoic acid	2.78	1.82	2.11
C13 Tridecanoic acid	1.37	1.01	1.09
C14 Tetradecanoic acid	3.14	2.96	2.78
C15 Pentadecanoic acid	0.98	1.10	0.95
C16 Hexadecanoic acid	20.66	15.03	16.34
C17 Heptadecanoic acid	ND	ND	ND
C18 Octadecanoic acid	12.65	9.42	10.10
C19 Nonadecanoic acid	ND	ND	ND
C20 Eicosanoic acid	ND	ND	ND
C21 Heneicosanoic acid	ND	ND	ND
C22 Docosanoic acid	ND	ND	ND
C23 Tricosanoic acid	ND	ND	ND
C24 Tetracosanoic acid	0.22	0.33	0.25
C25 Pentacosanoic acid	ND	ND	ND
C26 Hexacosanoic acid	ND	ND	ND
C27 Heptacosanoic acid	ND	ND	ND
Abietic acid	ND	ND	ND
Octacosanoic acid	ND	ND	ND
Nonacosanoic acid	ND	ND	ND
Triacontanoic acid	ND	ND	ND
Pinonic acid	ND	ND	ND
Palmitoleic acid (C16:1)	ND	1.74	0.76
Oleic acid (C18:1)	ND	ND	ND
Linoleic acid (C18:2)	ND	ND	ND
Linolenic acid	ND	ND	ND
Pimaric acid	ND	73.01	43.00
Sandaracopimaric acid	ND	ND	ND
Isopimaric acid	ND	ND	ND
6,8,11,13-Abietatetraen-18-oic acid	ND	ND	ND
Dehydroabietic acid	ND	ND	ND
Levogluconan (TMS derivative)	ND	ND	ND
Cholesterol (TMS derivative)	ND	ND	ND
Stigmasterol (TMS derivative)	ND	ND	ND
Monopalmitin (TMS derivative)	ND	ND	ND
Monoolein (TMS derivative)	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

<b>Compound</b>	<b>August 8</b>	<b>August 9</b>	<b>Denuder (Composite</b>
	<b>Extract Concentration</b> <b>D0619001&amp;2</b> <b>(ng/μL)</b>	<b>Extract Concentration</b> <b>D710001&amp;2</b> <b>(ng/μL)</b>	<b>of August 8 and</b> <b>August 9)</b> <b>Compound Emission</b> <b>Rate</b> <b>(μg/kg)</b>
Monostearin (TMS derivative)	ND	ND	ND
Glycerine (TMS derivative)	ND	ND	ND
β-Sitosterol (TMS derivative)	ND	ND	ND
Sitostenone (TMS derivative)	ND	ND	ND
α-Amyrin	ND	ND	ND
β-Amyrin	ND	ND	ND
Unresolved Complex Mixture (UCM)	ND	ND	ND
2-methylnonadecane	ND	ND	ND
3-methylnonadecane	ND	ND	ND
iso-docosane	ND	ND	ND
anteiso-docosane	1.88	ND	0.68
iso-tricosane	1.82	1.77	1.41
anteiso-tricosane	11.15	5.65	6.44
iso-tetracosane	1.26	0.88	0.83
anteiso-tetracosane	0.96	0.93	0.74
iso-pentacosane	0.82	0.61	0.56
anteiso-pentacosane	1.00	0.97	0.77
iso-hexacosane	0.61	0.52	0.44
anteiso-hexacosane	0.78	0.65	0.56
iso-heptacosane	0.28	ND	0.10
anteisoheptacosane	0.50	ND	0.18
iso-Octacosane	ND	ND	ND
anteiso-Octacosane	ND	ND	ND
iso-nonacosane	1.04	ND	0.38
anteiso-nonacosane	1.48	ND	0.54
iso-triacontane	ND	ND	ND
anteiso-triacontane	ND	ND	ND
iso-hentriacontane	ND	ND	ND
anteiso-hentriacontane	ND	ND	ND
iso-dotriacontane	ND	ND	ND
anteiso-dotriacontane	ND	ND	ND
iso-tritriacontane	ND	ND	ND
anteiso-tritriacontane	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)****Quartz Filters (After Denuder)**

Mass of fuel (kg)	224,717
Dilution ratio	49.05
Total air introduced (m <sup>3</sup> )	172,275.6
Time (min)	617.55
Flow rate (L/min)	17.62
Extract Volume (μL)	2.50

Compounds	August 8 and August 9 Composite Extract Concentration	Compound Emission Rate
	(ng/μL)	(μg/kg)
Naphthalene	0.31	0.26
Acenaphthylene	0.03	0.02
Acenaphthene	ND	ND
Fluorene	ND	ND
Phenanthrene	0.03	0.02
Anthracene	ND	ND
Fluoranthene	0.01	0.01
Pyrene	ND	ND
Benzo[a]anthracene	ND	ND
Chrysene	ND	ND
Benzo[b]fluoranthene	ND	ND
Benzo[k]fluoranthene	ND	ND
Benzo[a]pyrene	ND	ND
Benzo[ghi]perylene	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND
Indeno[1,2,3-cd]fluoranthene	ND	ND
Dibenzo[a,h]anthracene	ND	ND
Coronene	ND	ND
1-Methylnaphthalene	0.10	0.09
2-Methylnaphthalene	0.08	0.07
2,7-Dimethylnaphthalene	ND	ND
1,3-Dimethylnaphthalene	ND	ND
2,6-Dimethylnaphthalene	ND	ND
9-Methylantracene	ND	ND
Methylfluorene	ND	ND
bis(2-Ethylhexyl)phthalate	2.88	2.48
Butyl benzyl phthalate	1.69	1.46
Diethyl phthalate	0.55	0.48
Dimethyl phthalate	ND	ND
Di- <i>n</i> -butyl phthalate	0.58	0.50
Di- <i>n</i> -octyl phthalate	ND	ND
Octylcyclohexane	ND	ND
Decylcyclohexane	ND	ND
Tridecylcyclohexane	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compounds	August 8 and August 9 Composite	
	Extract Concentration (ng/μL)	Compound Emission Rate (μg/kg)
Nonadecylcyclohexane	ND	ND
Norpristane	ND	ND
Pristane	ND	ND
Phytane	ND	ND
Squalane	ND	ND
ABB-20R-C27-Cholestane	ND	ND
BAA-20R-C27-Cholestane	ND	ND
AAA-20S-C27-Cholestane	ND	ND
AAA-20R-C27-Cholestane	ND	ND
ABB-20R-C28-Methylcholestane	ND	ND
ABB-20R-C29-Ethylcholestane	ND	ND
17A(H)-22, 29, 30-Trisnorhopane	ND	ND
17B(H)-21A(H)-30-Norhopane	ND	ND
17B(H)-21B(H)-Hopane	ND	ND
17B(H)-21A(H)-Hopane	ND	ND
17A(H)-21B(H)-Hopane	ND	ND
<i>n</i> -Decane (C10)	ND	ND
<i>n</i> -Undecane (C11)	ND	ND
<i>n</i> -Dodecane (C12)	ND	ND
<i>n</i> -Tridecane (C13)	ND	ND
<i>n</i> -Tetradecane (C14)	0.1	0.09
<i>n</i> -Pentadecane (C15)	0.135	0.12
<i>n</i> -Hexadecane (C16)	0.12	0.10
<i>n</i> -Heptadecane (C17)	0.1	0.09
<i>n</i> -Octadecane (C18)	0.09	0.08
<i>n</i> -Nonadecane (C19)	ND	ND
<i>n</i> -Eicosane (C20)	0.305	0.26
<i>n</i> -Heneicosane (C21)	0.32	0.28
<i>n</i> -Docosane (C22)	0.79	0.68
<i>n</i> -Tricosane (C23)	3.935	3.40
<i>n</i> -Tetracosane (C24)	23.8	20.56
<i>n</i> -Pentacosane (C25)	46.97	40.58
<i>n</i> -Hexacosane (C26)	52.335	45.21
<i>n</i> -Heptacosane (C27)	34.81	30.07
<i>n</i> -Octacosane (C28)	21.135	18.26
<i>n</i> -Nonacosane (C29)	10.045	8.68
<i>n</i> -Triacontane (C30)	5.21	4.50
<i>n</i> -Hentriacontane (C31)	3.405	2.94
<i>n</i> -Dotriacontane (C32)	1.255	1.08
<i>n</i> -Tritriacontane (C33)	0.485	0.42
<i>n</i> -Tetratriacontane (C34)	0.215	0.19
<i>n</i> -Pentatriacontane (C35)	0.28	0.24

ND = Compound not detected.

(Continued)



**Table F-2. (Continued)**

Compounds	August 8 and August 9 Composite	
	Extract Concentration (ng/μL)	Compound Emission Rate (μg/kg)
<i>n</i> -Hexatriacontane (C36)	0.095	0.08
<i>n</i> -Tetracontane (C40)	ND	ND
3-Methylnonadecane	ND	ND
2-Methylnonadecane	ND	ND
Cyclopenta[cd]pyrene	ND	ND
Dibenzo[a,e]pyrene	ND	ND
Pyrene	ND	ND
Benzo[a]pyrene	ND	ND
Methylfluoranthene	ND	ND
Methylchrysene	ND	ND
Retene	ND	ND
Anthroquinone	ND	ND
9-Fluorenone	ND	ND
Benzo[a]anthracene-7,12-dione	ND	ND
1,8-Naphthalic anhydride	ND	ND
Squalene	ND	ND
1-Octadecene	ND	ND
Benzo[e]pyrene	ND	ND
Oxalic acid (C2)	ND	ND
Malonic acid (C3)	ND	ND
Maleic acid (C3=)	ND	ND
Fumaric acid (C4=)	ND	ND
Succinic acid (C4) Butanedioic acid	ND	ND
Glutaric acid (C5) Pentanedioic acid	ND	ND
Adipic acid (C6) Hexanedioic acid	ND	ND
Pimelic acid (C7) Heptanedioic acid	ND	ND
Suberic acid (C8) Octanedioic acid	ND	ND
Azelaic acid (C9) Nonanedioic acid	ND	ND
Sebacic acid (C10) Decanedioic acid	ND	ND
Phthalic acid (1,2)	ND	ND
Isophthalic acid (1,3)	ND	ND
Terephthalic acid (1,4)	ND	ND
1,2,4-Benzenetricarboxylic acid	ND	ND
1,2,4,5-Benzenetetracarboxylic acid	ND	ND
Methylphthalic acid	ND	ND
C6 Hexanoic acid	ND	ND
C8 Octanoic acid	ND	ND
C9 Nonanoic acid	ND	ND
C10 Decanoic acid	ND	ND
C11 Undecanoic acid	ND	ND
C12 Dodecanoic acid	0.15	0.15
C13 Tridecanoic acid	0.09	0.09

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compounds	August 8 and August 9 Composite	
	Extract Concentration (ng/μL)	Compound Emission Rate (μg/kg)
C14 Tetradecanoic acid	0.17	0.16
C15 Pentadecanoic acid	0.11	0.11
C16 Hexadecanoic acid	3.19	3.09
C17 Heptadecanoic acid	ND	ND
C18 Octadecanoic acid	6.03	5.83
C19 Nonadecanoic acid	ND	ND
C20 Eicosanoic acid	0.24	0.23
C21 Heneicosanoic acid	ND	ND
C22 Docosanoic acid	ND	ND
C23 Tricosanoic acid	ND	ND
C24 Tetracosanoic acid	ND	ND
C25 Pentacosanoic acid	ND	ND
C26 Hexacosanoic acid	ND	ND
C27 Heptacosanoic acid	ND	ND
Abietic acid	ND	ND
Octacosanoic acid	ND	ND
Nonacosanoic acid	ND	ND
Triacontanoic acid	ND	ND
Pinonic acid	ND	ND
Palmitoleic acid (C16:1)	0.28	0.27
Oleic acid (C18:1)	0.5	0.48
Linoleic acid (C18:2)	0.28	0.27
Linolenic acid	ND	ND
Pimaric acid	ND	ND
Sandaracopimaric acid	ND	ND
Isopimaric acid	ND	ND
6,8,11,13-Abietatetraen-18-oic acid	ND	ND
Dehydroabietic acid	ND	ND
Levogluconan (TMS derivative)	2.12	12.31
Cholesterol (TMS derivative)	3.96	22.99
Stigmasterol (TMS derivative)	3.63	21.07
Monopalmitin (TMS derivative)	0.53	3.08
Monoolein (TMS derivative)	0.58	3.37
Monostearin (TMS derivative)	0.79	4.59
Glycerine (TMS derivative)	1.18	6.85
β-Sitosterol (TMS derivative)	ND	ND
Sitostenone (TMS derivative)	ND	ND
α-Amyrin	ND	ND
β-Amyrin	ND	ND
Unresolved Complex Mixture (UCM)	ND	ND
2-methylnonadecane	ND	ND
3-methylnonadecane	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compounds	August 8 and August 9 Composite	
	Extract Concentration (ng/μL)	Compound Emission Rate (μg/kg)
iso-docosane	ND	ND
anteiso-docosane	ND	ND
iso-tricosane	ND	ND
anteiso-tricosane	ND	ND
iso-tetracosane	1.17	1.01
anteiso-tetracosane	0.495	0.43
iso-pentacosane	2.885	2.49
anteiso-pentacosane	1.745	1.51
iso-hexacosane	2.705	2.34
anteiso-hexacosane	2.205	1.91
iso-heptacosane	2.005	1.73
anteisoheptacosane	1.635	1.41
iso-Octacosane	0.89	0.77
anteiso-Octacosane	0.93	0.80
iso-nonacosane	0.555	0.48
anteiso-nonacosane	0.36	0.31
iso-triacontane	0.325	0.28
anteiso-triacontane	0.25	0.22
iso-hentriacontane	0.11	0.10
anteiso-hentriacontane	0.08	0.07
iso-dotriacontane	0.065	0.06
anteiso-dotriacontane	0.045	0.04
iso-tritriacontane	ND	ND
anteiso-tritriacontane	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

**Dilution Air Quartz Filters**

Mass of fuel (kg)	224,717
Dilution ratio	48.05
Total air introduced (m <sup>3</sup> )	172,275.6
Time (min)	617.55
Flow rate (L/min)	17.585
Extract Volume (μL)	260

Compounds	August 8 and August 9 Composite Extract Concentration Q051200Q-Q051200T	Compound Emission Rate	Compound Emission Rate Corrected for Dilution Air
	(ng/μL)	(μg/kg)	(μg/kg)
Naphthalene	0.36	0.35	-0.09
Acenaphthylene	0.02	0.02	0.00
Acenaphthene	ND	ND	ND
Fluorene	ND	ND	ND
Phenanthrene	0.03	0.03	-0.01
Anthracene	ND	ND	ND
Fluoranthene	ND	ND	0.01
Pyrene	ND	ND	ND
Benzo[a]anthracene	ND	ND	ND
Chrysene	ND	ND	ND
Benzo[b]fluoranthene	ND	ND	ND
Benzo[k]fluoranthene	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND
Benzo[ghi]perylene	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND
Indeno[1,2,3-cd]fluoranthene	ND	ND	ND
Dibenzo[a,h]anthracene	ND	ND	ND
Coronene	ND	ND	ND
1-Methylnaphthalene	0.06	0.06	0.03
2-Methylnaphthalene	0.10	0.10	-0.03
2,7-Dimethylnaphthalene	ND	ND	ND
1,3-Dimethylnaphthalene	ND	ND	ND
2,6-Dimethylnaphthalene	ND	ND	ND
9-Methylanthracene	ND	ND	ND
Methylfluorene	0.02	0.02	-0.02
bis(2-Ethylhexyl)phthalate	2.35	2.29	0.19
Butyl benzyl phthalate	0.73	0.71	0.74
Diethyl phthalate	0.88	0.86	-0.38
Dimethyl phthalate	0.05	0.05	-0.05
Di- <i>n</i> -butyl phthalate	0.72	0.70	-0.21
Di- <i>n</i> -octyl phthalate	ND	ND	ND
Octylcyclohexane	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compounds	August 8 and August 9 Composite Extract Concentration Q051200Q-Q051200T	Compound Emission Rate	Compound Emission Rate Corrected for Dilution Air
	(ng/μL)	(μg/kg)	(μg/kg)
Decylcyclohexane	ND	ND	ND
Tridecylcyclohexane	ND	ND	ND
Nonadecylcyclohexane	ND	ND	ND
Norpristane	ND	ND	ND
Pristane	0.04	0.04	-0.04
Phytane	0.08	0.08	-0.08
Squalane	0.17	0.17	-0.17
ABB-20R-C27-Cholestane	ND	ND	ND
BAA-20R-C27-Cholestane	ND	ND	ND
AAA-20S-C27-Cholestane	ND	ND	ND
AAA-20R-C27-Cholestane	ND	ND	ND
ABB-20R-C28-Methylcholestane	ND	ND	ND
ABB-20R-C29-Ethylcholestane	ND	ND	ND
17A(H)-22, 29, 30-Trisnorhopane	ND	ND	ND
17B(H)-21A(H)-30-Norhopane	ND	ND	ND
17B(H)-21B(H)-Hopane	ND	ND	ND
17B(H)-21A(H)-Hopane	ND	ND	ND
17A(H)-21B(H)-Hopane	ND	ND	ND
<i>n</i> -Decane (C10)	ND	ND	ND
<i>n</i> -Undecane (C11)	ND	ND	ND
<i>n</i> -Dodecane (C12)	ND	ND	ND
<i>n</i> -Tridecane (C13)	ND	ND	ND
<i>n</i> -Tetradecane (C14)	0.15	0.15	-0.06
<i>n</i> -Pentadecane (C15)	0.13	0.13	-0.01
<i>n</i> -Hexadecane (C16)	0.11	0.11	0.00
<i>n</i> -Heptadecane (C17)	0.08	0.08	0.01
<i>n</i> -Octadecane (C18)	0.12	0.12	-0.04
<i>n</i> -Nonadecane (C19)	0.58	0.57	-0.57
<i>n</i> -Eicosane (C20)	1.73	1.69	-1.43
<i>n</i> -Heneicosane (C21)	1.89	1.85	-1.57
<i>n</i> -Docosane (C22)	0.98	0.96	-0.27
<i>n</i> -Tricosane (C23)	0.58	0.57	2.83
<i>n</i> -Tetracosane (C24)	0.7	0.68	19.88
<i>n</i> -Pentacosane (C25)	0.92	0.90	39.68
<i>n</i> -Hexacosane (C26)	1.23	1.20	44.01
<i>n</i> -Heptacosane (C27)	1.33	1.30	28.78
<i>n</i> -Octacosane (C28)	1.29	1.26	17.00
<i>n</i> -Nonacosane (C29)	1.08	1.05	7.62
<i>n</i> -Triacontane (C30)	0.64	0.62	3.88
<i>n</i> -Hentriacontane (C31)	0.7	0.68	2.26

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compounds	August 8 and August 9 Composite Extract Concentration Q051200Q-Q051200T	Compound Emission Rate	Compound Emission Rate Corrected for Dilution Air
	(ng/μL)	(μg/kg)	(μg/kg)
<i>n</i> -Dotriacontane (C32)	0.31	0.30	0.78
<i>n</i> -Tritriacontane (C33)	0.15	0.15	0.27
<i>n</i> -Tetratriacontane (C34)	0.08	0.08	0.11
<i>n</i> -Pentatriacontane (C35)	ND	ND	0.24
<i>n</i> -Hexatriacontane (C36)	ND	ND	0.08
<i>n</i> -Tetracontane (C40)	ND	ND	ND
3-Methylnonadecane	0.42	0.41	-0.41
2-Methylnonadecane	0.29	0.28	-0.28
Cyclopenta[cd]pyrene	ND	ND	ND
Dibenzo[a,e]pyrene	ND	ND	ND
Pyrene	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND
Methylfluoranthene	ND	ND	ND
Methylchrysene	ND	ND	ND
Retene	ND	ND	ND
Anthroquinone	ND	ND	ND
9-Fluorenone	ND	ND	ND
Benzo[a]anthracene-7,12-dione	ND	ND	ND
1,8-Naphthalic anhydride	ND	ND	ND
Squalene	0.71	0.69	-0.69
1-Octadecene	ND	ND	ND
Benzo[e]pyrene	ND	ND	ND
Oxalic acid (C2)	ND	ND	ND
Malonic acid (C3)	ND	ND	ND
Maleic acid (C3=)	ND	ND	ND
Fumaric acid (C4=)	ND	ND	ND
Succinic acid (C4) Butanedioic acid	ND	ND	ND
Glutaric acid (C5) Pentanedioic acid	ND	ND	ND
Adipic acid (C6) Hexanedioic acid	ND	ND	ND
Pimelic acid (C7) Heptanedioic acid	ND	ND	ND
Suberic acid (C8) Octanedioic acid	ND	ND	ND
Azelaic acid (C9) Nonanedioic acid	ND	ND	ND
Sebacic acid (C10) Decanedioic acid	ND	ND	ND
Phthalic acid (1,2)	1.06	1.08	-1.08
Isophthalic acid (1,3)	ND	ND	ND
Terephthalic acid (1,4)	ND	ND	ND
1,2,4-Benzenetricarboxylic acid	ND	ND	ND
1,2,4,5-Benzenetetracarboxylic acid	ND	ND	ND
Methylphthalic acid	ND	ND	ND
C6 Hexanoic acid	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compounds	August 8 and August 9 Composite Extract Concentration Q051200Q-Q051200T	Compound Emission Rate	Compound Emission Rate Corrected for Dilution Air
	(ng/μL)	(μg/kg)	(μg/kg)
C8 Octanoic acid	ND	ND	ND
C9 Nonanoic acid	0.08	0.08	-0.08
C10 Decanoic acid	0.09	0.09	-0.09
C11 Undecanoic acid	0.03	0.03	-0.03
C12 Dodecanoic acid	0.38	0.39	-0.24
C13 Tridecanoic acid	0.03	0.03	0.06
C14 Tetradecanoic acid	0.47	0.48	-0.31
C15 Pentadecanoic acid	0.12	0.12	-0.02
C16 Hexadecanoic acid	1.33	1.35	1.73
C17 Heptadecanoic acid	ND	ND	ND
C18 Octadecanoic acid	0.44	0.45	5.39
C19 Nonadecanoic acid	ND	ND	ND
C20 Eicosanoic acid	0.02	0.02	0.21
C21 Heneicosanoic acid	ND	ND	ND
C22 Docosanoic acid	ND	ND	ND
C23 Tricosanoic acid	ND	ND	ND
C24 Tetracosanoic acid	ND	ND	ND
C25 Pentacosanoic acid	ND	ND	ND
C26 Hexacosanoic acid	ND	ND	ND
C27 Heptacosanoic acid	ND	ND	ND
Abietic acid	ND	ND	ND
Octacosanoic acid	ND	ND	ND
Nonacosanoic acid	ND	ND	ND
Triacontanoic acid	ND	ND	ND
Pinonic acid	ND	ND	ND
Palmitoleic acid (C16:1)	0.23	0.23	0.04
Oleic acid (C18:1)	0.27	0.28	0.21
Linoleic acid (C18:2)	0.16	0.16	0.11
Linolenic acid	ND	ND	ND
Pimaric acid	ND	ND	ND
Sandaracopimaric acid	ND	ND	ND
Isopimaric acid	ND	ND	ND
6,8,11,13-Abietatetraen-18-oic acid	ND	ND	ND
Dehydroabietic acid	15.98	16.28	-16.28
Levoglucosan (TMS derivative)	1.87	11.43	0.88
Cholesterol (TMS derivative)	3.42	20.90	2.09
Stigmasterol (TMS derivative)	2.97	18.15	2.92
Monopalmitin (TMS derivative)	0.45	2.75	0.33
Monoolein (TMS derivative)	0.4	2.45	0.92
Monostearin (TMS derivative)	0.51	3.12	1.47

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

<b>Compounds</b>	<b>August 8 and August 9 Composite Extract Concentration Q051200Q-Q051200T (ng/μL)</b>	<b>Compound Emission Rate (μg/kg)</b>	<b>Compound Emission Rate Corrected for Dilution Air (μg/kg)</b>
Glycerine (TMS derivative)	0.98	5.99	0.86
β-Sitosterol (TMS derivative)	ND	ND	ND
Sitostenone (TMS derivative)	ND	ND	ND
α-Amyrin	ND	ND	ND
β-Amyrin	ND	ND	ND
Unresolved Complex Mixture (UCM)	ND	ND	ND
2-methylnonadecane	0.29	0.28	-0.28
3-methylnonadecane	0.42	0.41	-0.41
iso-docosane	ND	ND	ND
anteiso-docosane	0.18	0.18	-0.18
iso-tricosane	ND	ND	ND
anteiso-tricosane	ND	ND	ND
iso-tetracosane	ND	ND	1.01
anteiso-tetracosane	ND	ND	0.43
iso-pentacosane	ND	ND	2.49
anteiso-pentacosane	ND	ND	1.51
iso-hexacosane	ND	ND	2.34
anteiso-hexacosane	ND	ND	1.91
iso-heptacosane	ND	ND	1.73
anteisoheptacosane	ND	ND	1.41
iso-Octacosane	ND	ND	0.77
anteiso-Octacosane	ND	ND	0.80
iso-nonacosane	0.05	0.05	0.43
anteiso-nonacosane	ND	ND	0.31
iso-triacontane	ND	ND	0.28
anteiso-triacontane	ND	ND	0.22
iso-hentriacontane	ND	ND	0.10
anteiso-hentriacontane	ND	ND	0.07
iso-dotriacontane	ND	ND	0.06
anteiso-dotriacontane	ND	ND	0.04
iso-tritriacontane	ND	ND	ND
anteiso-tritriacontane	ND	ND	ND

ND = Compound not detected.

(Continued)



Table F-2. (Continued)

**PUF Plugs**

<u>Mass of fuel (kg)</u>	<u>August 8</u> <u>Dilution Ratio</u>	<u>Tot. Air Intro</u> <u>(m3)</u>	<u>August 9</u> <u>Dilution Ratio</u>
224717	49.05	172275.6	48.05
<u>Time (min)</u>	<u>PUF Flow rate</u> <u>(L/min)</u>	<u>PUFs Flow rate - August 9</u> <u>(L/min)</u>	
617.55	17.62	17.585	
	<u>Extract Volume</u>	<u>Extract Volume</u>	<u>Extract Volume</u>
	250.00 µL	245.00 µL	240 µL      255 µL

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<b>Compound</b>	<b>August 8</b> <b>Concentration</b> <b>P071900AB</b> <b>(ng/µL)</b>	<b>August 9</b> <b>Concentration</b> <b>P073100AB</b> <b>(ng/µL)</b>	<b>Compound</b> <b>Emission Rate</b> <b>(µg/kg)</b>	<b>August 8</b> <b>Concentration</b> <b>P073100GH</b> <b>(ng/µL)</b>	<b>August 9</b> <b>Concentration</b> <b>P080100AB</b> <b>(ng/µL)</b>	<b>Compound</b> <b>Dilution Air</b> <b>Emission Rate</b> <b>(µg/kg)</b>	<b>Corrected</b> <b>Compound</b> <b>Emission Rate</b> <b>(µg/kg)</b>
Naphthalene	2.65	1.49	3.55	0.56	0.94	1.27	2.28
Acenaphthylene	ND	ND	ND	ND	ND	ND	ND
Acenaphthene	ND	0.64	0.54	ND	ND	ND	0.54
Fluorene	2.33	ND	2.01	ND	ND	ND	2.01
Phenanthrene	ND	3.46	2.93	0.62	0.56	0.99	1.94
Anthracene	ND	ND	ND	ND	0.06	0.05	ND
Fluoranthene	0.05	0.25	0.25	ND	0.05	0.04	0.21
Pyrene	0.03	0.12	0.13	ND	0.04	0.03	0.09
Benzo[a]anthracene	ND	ND	ND	ND	ND	ND	ND
Chrysene	ND	ND	ND	ND	ND	ND	ND
Benzo[b]fluoranthene	ND	ND	ND	ND	ND	ND	ND
Benzo[k]fluoranthene	ND	ND	ND	ND	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND	ND	ND	ND	ND
Benzo[ghi]perylene	ND	ND	ND	ND	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND	ND	ND	ND	ND
Indeno[1,2,3-cd]fluoranthene	ND	ND	ND	ND	ND	ND	ND
Dibenzo[a,h]anthracene	ND	ND	ND	ND	ND	ND	ND
Coronene	ND	ND	ND	ND	ND	ND	ND
1-Methylnaphthalene	3.27	0.92	3.60	0.26	0.32	0.49	3.12
2-Methylnaphthalene	4.60	1.53	5.27	0.49	0.73	1.03	4.24

ND = Compound not detected.

(Continued)

Table F-2. (Continued)

Compound	August 8 Concentration P071900AB (ng/μL)	August 9 Concentration P073100AB (ng/μL)	Compound Emission Rate (μg/kg)	August 8 Concentration P073100GH (ng/μL)	August 9 Concentration P080100AB (ng/μL)	Compound Dilution Air Emission Rate (μg/kg)	Corrected Compound Emission Rate (μg/kg)
2,7-Dimethylnaphthalene	1.50	ND	1.30	ND	0.7	0.61	0.69
1,3-Dimethylnaphthalene	2.13	0.83	2.54	ND	0.17	0.15	2.40
2,6-Dimethylnaphthalene	1.41	0.93	2.01	ND	0.14	0.12	1.88
9-Methylantracene	ND	ND	ND	ND	ND	ND	ND
Methylfluorene	ND	2.23	1.89	0.21	0.43	0.54	1.35
bis(2-Ethylhexyl)phthalate	3.02	2.49	4.72	0.77	ND	0.63	4.09
Butyl benzyl phthalate	1.94	4.98	5.89	0.72	0.95	1.41	4.48
Diethyl phthalate	16.53	22.12	33.01	1.49	0.85	1.95	31.06
Dimethyl phthalate	24.07	ND	20.80	ND	ND	ND	20.80
Di- <i>n</i> -butyl phthalate	0.83	2.94	3.21	0.83	1.54	2.01	1.20
Di- <i>n</i> -octyl phthalate	ND	ND	ND	ND	ND	ND	ND
Octylcyclohexane	ND	ND	ND	ND	ND	ND	ND
Decylcyclohexane	ND	ND	ND	ND	ND	ND	ND
Tridecylcyclohexane	ND	ND	ND	ND	ND	ND	ND
Nonadecylcyclohexane	ND	ND	ND	ND	ND	ND	ND
Norpristane	ND	ND	ND	ND	ND	ND	ND
Pristane	1.28	ND	1.11	0.79	0.54	1.11	0.00
Phytane	ND	ND	ND	1.22	1.35	2.16	ND
Squalane	ND	ND	ND	ND	ND	ND	ND
ABB-20R-C27-Cholestane	ND	ND	ND	ND	ND	ND	ND
BAA-20R-C27-Cholestane	ND	ND	ND	ND	ND	ND	ND
AAA-20S-C27-Cholestane	ND	ND	ND	ND	ND	ND	ND
AAA-20R-C27-Cholestane	ND	ND	ND	ND	ND	ND	ND
ABB-20R-C28-Methylcholestane	ND	ND	ND	ND	ND	ND	ND
ABB-20R-C29-Ethylcholestane	ND	ND	ND	ND	ND	ND	ND
17A(H)-22, 29, 30-Trisnorhopane	ND	ND	ND	ND	ND	ND	ND
17B(H)-21A(H)-30-Norhopane	ND	ND	ND	ND	ND	ND	ND
17B(H)-21B(H)-Hopane	ND	ND	ND	ND	ND	ND	ND

ND = Compound not detected.

(Continued)

Table F-2. (Continued)

Compound	August 8 Concentration P071900AB (ng/μL)	August 9 Concentration P073100AB (ng/μL)	Compound Emission Rate (μg/kg)	August 8 Concentration P073100GH (ng/μL)	August 9 Concentration P080100AB (ng/μL)	Compound Dilution Air Emission Rate (μg/kg)	Corrected Compound Emission Rate (μg/kg)
17B(H)-21A(H)-Hopane	ND	ND	ND	ND	ND	ND	ND
17A(H)-21B(H)-Hopane	ND	ND	ND	ND	ND	ND	ND
<i>n</i> -Decane (C10)	ND	ND	ND	ND	ND	ND	ND
<i>n</i> -Undecane (C11)	ND	ND	ND	ND	ND	ND	ND
<i>n</i> -Dodecane (C12)	ND	ND	ND	ND	ND	ND	ND
<i>n</i> -Tridecane (C13)	2.77	ND	2.39	2.2	1.25	2.87	ND
<i>n</i> -Tetradecane (C14)	1.08	0.33	1.21	1.34	1.31	2.22	ND
<i>n</i> -Pentadecane (C15)	3.84	0.55	3.78	1.28	1.09	1.98	1.80
<i>n</i> -Hexadecane (C16)	6.02	2.56	7.37	1.51	1.88	2.86	4.51
<i>n</i> -Heptadecane (C17)	4.69	1.56	5.37	1.35	1.5	2.40	2.98
<i>n</i> -Octadecane (C18)	5.74	2.36	6.96	1.37	1.59	2.49	4.47
<i>n</i> -Nonadecane (C19)	11.02	6.23	14.80	2.01	2.98	4.21	10.58
<i>n</i> -Eicosane (C20)	3.26	1.47	4.06	1.28	2.29	3.02	1.04
<i>n</i> -Heneicosane (C21)	3.72	1.49	4.48	0.99	1.08	1.74	2.74
<i>n</i> -Docosane (C22)	7.01	2.83	8.45	0.74	ND	13.04	ND
<i>n</i> -Tricosane (C23)	17.98	5.55	20.23	1.64	ND	1.34	18.90
<i>n</i> -Tetracosane (C24)	14.24	3.12	14.94	1.02	14.38	13.27	1.68
<i>n</i> -Pentacosane (C25)	6.42	3.65	8.64	1.91	2.03	3.31	5.33
<i>n</i> -Hexacosane (C26)	4.34	4.33	7.42	3.54	ND	2.88	4.53
<i>n</i> -Heptacosane (C27)	5.94	6.21	10.39	5.42	0.27	4.65	5.74
<i>n</i> -Octacosane (C28)	6.56	6.26	10.97	6.1	4.11	8.52	2.45
<i>n</i> -Nonacosane (C29)	7.96	6.25	12.17	5.84	4.43	8.59	3.58
<i>n</i> -Triacontane (C30)	2.87	1.86	4.05	2.06	1.47	2.95	1.11
<i>n</i> -Hentriacontane (C31)	2.65	1.42	3.49	1.2	1.16	1.98	1.51
<i>n</i> -Dotriacontane (C32)	3.37	1.43	4.12	1.27	ND	1.03	3.09
<i>n</i> -Tritriacontane (C33)	1.45	0.78	1.91	0.78	ND	0.63	1.28
<i>n</i> -Tetraatriacontane (C34)	3.19	0.51	3.19	0.51	ND	0.42	2.77
<i>n</i> -Pentatriacontane (C35)	4.09	0.87	4.27	1.82	ND	1.48	2.79
<i>n</i> -Hexatriacontane (C36)	ND	ND	ND	1.37	ND	1.12	ND
<i>n</i> -Tetracontane (C40)	ND	ND	ND	ND	ND	ND	ND
3-Methylnonadecane	ND	ND	ND	ND	0.83	0.72	ND
2-Methylnonadecane	ND	ND	ND	ND	0.37	0.32	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compound	August 8 Concentration P071900AB (ng/μL)	August 9 Concentration P073100AB (ng/μL)	Compound Emission Rate (μg/kg)	August 8 Concentration P073100GH (ng/μL)	August 9 Concentration P080100AB (ng/μL)	Compound Dilution Air Emission Rate (μg/kg)	Corrected Compound Emission Rate (μg/kg)
Cyclopenta[cd]pyrene	ND	ND	ND	0.91	ND	0.74	ND
Dibenzo[a,e]pyrene	ND	ND	ND	ND	ND	ND	ND
Pyrene	ND	0.04	0.03	ND	ND	ND	0.03
Benzo[a]pyrene	ND	ND	ND	ND	ND	ND	ND
Methylfluoranthene	ND	ND	ND	ND	ND	ND	ND
Methylchrysene	ND	ND	ND	ND	ND	ND	ND
Retene	ND	ND	ND	ND	ND	ND	ND
Anthroquinone	ND	ND	ND	ND	ND	ND	ND
9-Fluorenone	1.55	ND	1.34	ND	ND	ND	1.34
Benzo[a]anthracene-7,12- dione	ND	ND	ND	ND	ND	ND	ND
1,8-Naphthalic anhydride	ND	ND	ND	ND	ND	ND	ND
Squalene	ND	4.44	3.76	ND	4.47	3.87	ND
1-Octadecene	ND	ND	ND	ND	ND	ND	ND
Benzo[e]pyrene	ND	ND	ND	ND	ND	ND	ND
Oxalic acid (C2)	ND	ND	ND	ND	ND	ND	ND
Malonic acid (C3)	ND	ND	ND	ND	ND	ND	ND
Maleic acid (C3=)	ND	ND	ND	ND	ND	ND	ND
Fumaric acid (C4=)	ND	ND	ND	ND	ND	ND	ND
Succinic acid (C4)	ND	ND	ND	ND	ND	ND	ND
Butanedioic acid	ND	ND	ND	ND	ND	ND	ND
Glutaric acid (C5)	ND	ND	ND	ND	ND	ND	ND
Pentanedioic acid	ND	ND	ND	ND	ND	ND	ND
Adipic acid (C6) Hexanedioic acid	ND	ND	ND	ND	ND	ND	ND
Pimelic acid (C7)	ND	ND	ND	ND	ND	ND	ND
Heptanedioic acid	ND	ND	ND	ND	ND	ND	ND
Suberic acid (C8) Octanedioic acid	ND	ND	ND	ND	ND	ND	ND
Azelaic acid (C9)	ND	ND	ND	ND	ND	ND	ND
Nonanedioic acid	ND	ND	ND	ND	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compound	August 8 Concentration P071900AB (ng/μL)	August 9 Concentration P073100AB (ng/μL)	Compound Emission Rate (μg/kg)	August 8 Concentration P073100GH (ng/μL)	August 9 Concentration P080100AB (ng/μL)	Compound Dilution Air Emission Rate (μg/kg)	Corrected Compound Emission Rate (μg/kg)
Sebacic acid (C10)							
Decanedioic acid	ND	ND	ND	ND	ND	ND	ND
Phthalic acid (1,2)	ND	ND	ND	ND	ND	ND	ND
Isophthalic acid (1,3)	ND	ND	ND	ND	ND	ND	ND
Terephthalic acid (1,4)	ND	3.78	2.37	ND	ND	ND	2.37
1,2,4-Benzenetricarboxylic acid	ND	ND	ND	ND	ND	ND	ND
1,2,4,5- Benzenetetracarboxylic acid	ND	ND	ND	ND	ND	ND	ND
Methylphthalic acid	ND	ND	ND	ND	ND	ND	ND
C6 Hexanoic acid	ND	ND	ND	ND	ND	ND	ND
C8 Octanoic acid	2.12	2.66	4.09	0.5	0.69	1.18	2.91
C9 Nonanoic acid	1.89	3.34	4.25	0.61	0.9	1.50	2.76
C10 Decanoic acid	ND	0.38	0.24	0.24	0.25	0.48	ND
C11 Undecanoic acid	0.28	0.51	0.64	0.07	0.09	0.16	0.48
C12 Dodecanoic acid	0.78	1.96	2.12	0.32	0.6	0.92	1.20
C13 Tridecanoic acid	ND	0.51	0.32	0.05	0.08	0.13	0.19
C14 Tetradecanoic acid	1.24	1.33	2.25	0.31	0.85	1.17	1.08
C15 Pentadecanoic acid	0.49	0.53	0.89	0.14	0.41	0.55	0.34
C16 Hexadecanoic acid	4.49	4.00	7.64	1.57	4.01	5.60	2.03
C17 Heptadecanoic acid	ND	0.51	0.32	0.07	ND	0.06	0.26
C18 Octadecanoic acid	2.08	2.36	3.86	1.41	3.2	4.62	ND
C19 Nonadecanoic acid	ND	0.04	0.03	0.02	ND	0.02	0.01
C20 Eicosanoic acid	0.09	0.13	0.18	0.14	0.15	0.28	ND
C21 Heneicosanoic acid	ND	ND	ND	ND	ND	ND	ND
C22 Docosanoic acid	0.06	ND	0.07	ND	ND	ND	0.07
C23 Tricosanoic acid	ND	ND	ND	ND	0.06	0.06	ND
C24 Tetracosanoic acid	0.14	0.18	0.27	0.08	0.24	0.32	ND
C25 Pentacosanoic acid	ND	0.04	0.03	ND	0.08	0.08	ND
C26 Hexacosanoic acid	ND	ND	ND	ND	ND	ND	ND
C27 Heptacosanoic acid	ND	ND	ND	ND	ND	ND	ND
Abietic acid	ND	ND	ND	ND	ND	ND	ND

ND = Compound not detected.

(Continued)

Table F-2. (Continued)

Compound	August 8 Concentration P071900AB (ng/μL)	August 9 Concentration P073100AB (ng/μL)	Compound Emission Rate (μg/kg)	August 8 Concentration P073100GH (ng/μL)	August 9 Concentration P080100AB (ng/μL)	Compound Dilution Air Emission Rate (μg/kg)	Corrected Compound Emission Rate (μg/kg)
Octacosanoic acid	ND	0.06	0.04	ND	ND	ND	0.04
Nonacosanoic acid	ND	ND	ND	ND	ND	ND	ND
Triacontanoic acid	ND	ND	ND	ND	ND	ND	ND
Pinonic acid	ND	ND	ND	ND	ND	ND	ND
Palmitoleic acid (C16:1)	ND	ND	ND	0.14	0.47	0.62	ND
Oleic acid (C18:1)	0.18	0.30	0.39	0.21	0.51	0.72	ND
Linoleic acid (C18:2)	ND	ND	ND	ND	ND	ND	ND
Linolenic acid	ND	ND	ND	ND	ND	ND	ND
Pimaric acid	ND	ND	ND	ND	ND	ND	ND
Sandaracopimaric acid	ND	ND	ND	ND	ND	ND	ND
Isopimaric acid	ND	ND	ND	ND	ND	ND	ND
6,8,11,13-Abietatetraen-18- oic acid	ND	ND	ND	ND	ND	ND	ND
Dehydroabietic acid	ND	ND	ND	6.93	ND	6.40	ND
Levoglucosan (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
Cholesterol (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
Stigmasterol (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
Monopalmitin (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
Monoolein (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
Monostearin (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
Glycerine (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
β-Sitosterol (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
Sitostenone (TMS derivative)	ND	ND	ND	ND	ND	ND	ND
α-Amyrin	ND	ND	ND	ND	ND	ND	ND
β-Amyrin	ND	ND	ND	ND	ND	ND	ND
Unresolved Complex Mixture (UCM)	ND	ND	ND	ND	ND	ND	ND
2-Methylnonadecane	ND	ND	ND	ND	ND	ND	ND
3-Methylnonadecane	ND	ND	ND	ND	ND	ND	ND
iso-Docosane	ND	ND	ND	ND	ND	ND	ND

ND = Compound not detected.

(Continued)

**Table F-2. (Continued)**

Compound	August 8 Concentration P071900AB (ng/μL)	August 9 Concentration P073100AB (ng/μL)	Compound Emission Rate (μg/kg)	August 8 Concentration P073100GH (ng/μL)	August 9 Concentration P080100AB (ng/μL)	Compound Dilution Air Emission Rate (μg/kg)	Corrected Compound Emission Rate (μg/kg)
anteiso-Docosane	ND	ND	ND	ND	ND	ND	ND
iso-Tricosane	ND	ND	ND	ND	ND	ND	ND
anteiso-Tricosane	ND	ND	ND	ND	ND	ND	ND
iso-Tetracosane	ND	ND	ND	ND	ND	ND	ND
anteiso-Tetracosane	ND	ND	ND	ND	ND	ND	ND
iso-Pentacosane	ND	ND	ND	ND	ND	ND	ND
anteiso-Pentacosane	ND	ND	ND	ND	ND	ND	ND
iso-Hexacosane	ND	ND	ND	ND	ND	ND	ND
anteiso-Hexacosane	ND	ND	ND	ND	ND	ND	ND
iso-Heptacosane	ND	ND	ND	ND	ND	ND	ND
anteisoHeptacosane	ND	ND	ND	ND	ND	ND	ND
iso-Octacosane	ND	ND	ND	ND	ND	ND	ND
anteiso-Dotriacontane	ND	ND	ND	ND	ND	ND	ND
iso-Tritriacontane	ND	ND	ND	ND	ND	ND	ND
anteiso-Tritriacontane	ND	ND	ND	ND	ND	ND	ND
ND = Compound not detected.							

**Appendix G**

**Supporting Data for Carbonyl Analysis**



**Table G-1. Carbonyl Compounds Analyzed by High Performance Liquid Chromatography**  
**Field Samples, August 8-9, 2000**  
**Results reported by individual carbonyl sampling tube.**

Compound	CAS No.	Residence Chamber				Residence Chamber	
		Blank	Blank	Front	Back	Front	Back
		8/8/00	8/9/00	Tube	Tube	Tube	Tube
µg							
formaldehyde	50-00-0	0.0425	0.0365	36.28	0.07	12.8735	0.0505
acetaldehyde	75-07-0	0.079	0.083	6.6595	0.165	2.5435	0.0965
acetone	67-64-1	0.184	0.2235	0.804	2.1695	0.2155	0.5535
propionaldehyde	123-38-6	ND	ND	0.8405	ND	0.428	ND
crotonaldehyde	4170-30-3	ND	ND	0.122	ND	0.068	ND
butyraldehyde	123-72-8	0.034	0.0875	0.51	0.293	0.3455	0.247
benzaldehyde	100-52-7	ND	0.0205	0.35	ND	0.202	ND
isovaleraldehyde	590-86-3	ND	ND	ND	ND	ND	ND
valeraldehyde	110-62-3	ND	ND	0.1585	0.013	0.072	ND
<i>o</i> -tolualdehyde	529-20-4	ND	ND	ND	ND	ND	ND
<i>m</i> -tolualdehyde	620-23-5	ND	0.028	0.1125	0.032	0.099	ND
<i>p</i> -tolualdehyde	104-87-0	ND	ND	ND	ND	0.0405	ND
hexaldehyde	66-25-1	0.016	0.018	0.1075	0.0185	0.0485	0.0205
2,5-dimethylbenz-aldehyde	5779-94-2	ND	ND	ND	ND	ND	ND
diacetyl	431-03-8	ND	ND	ND	ND	ND	ND
methacrolein	78-85-3	ND	ND	0.361	ND	0.185	ND
2-butanone	78-93-3	0.013	0.026	0.221	0.320	0.026	0.181
glyoxal	107-22-2	ND	ND	1.579	0.225	2.060	ND
acetophenone	98-86-2	ND	ND	0.905	ND	0.238	ND
methylglyoxal	78-98-8	ND	ND	0.553	ND	0.546	ND
octanal	124-13-0	ND	ND	ND	ND	ND	ND
nonanal	124-19-6	0.070	ND	0.506	0.077	0.379	0.102

ND = Not detected; compound not observed at detectable levels.

**Table G-2. Carbonyl Compounds Analyzed by High Performance Liquid Chromatography  
Field Samples, Generated August 8-9, 2000**

Compound	CAS No.	Blank	Residence Chamber	Blank	Residence Chamber
		8/8/00	Paired Tubes	8/9/00	Paired Tubes
		µg	µg	µg	µg
formaldehyde	50-00-0	0.0425	36.35	0.0365	12.924
acetaldehyde	75-07-0	0.079	6.8245	0.083	2.640
acetone	67-64-1	0.184	2.9735	0.2235	0.7690
propionaldehyde	123-38-6	ND	0.8405	ND	0.4280
crotonaldehyde	4170-30-3	ND	0.1220	ND	0.0680
butyraldehyde	123-72-8	0.034	0.8030	0.0875	0.5925
benzaldehyde	100-52-7	ND	0.3500	0.0205	0.2020
isovaleraldehyde	590-86-3	ND	ND	ND	ND
valeraldehyde	110-62-3	ND	0.1715	ND	0.0720
<i>o</i> -tolualdehyde	529-20-4	ND	ND	ND	ND
<i>m</i> -tolualdehyde	620-23-5	ND	0.1445	0.028	0.0990
<i>p</i> -tolualdehyde	104-87-0	ND	ND	ND	0.0405
hexaldehyde	66-25-1	0.016	0.1260	0.018	0.0690
2,5-dimethylbenz- aldehyde	5779-94-2	ND	ND	ND	ND
diacetyl	431-03-8	ND	ND	ND	ND
methacrolein	78-85-3	ND	0.3610	ND	0.1850
2-butanone	78-93-3	0.013	0.5410	0.026	0.2070
glyoxal	107-22-2	ND	1.8040	ND	2.0600
acetophenone	98-86-2	ND	0.9050	ND	0.2380
methylglyoxal	78-98-8	ND	0.5530	ND	0.5460
octanal	124-13-0	ND	ND	ND	ND
nonanal	124-19-6	0.070	0.5830	ND	0.4810
<b>Total Speciated</b>		0.3595	53.4525	0.5230	21.4680
<b>Total Unspeciated</b>		2.3270	6.8975	1.4755	4.6515
<b>Total Speciated + Unspeciated</b>		2.6865	60.3500	1.9985	25.1195

ND = Not detected; compound not observed in performance of the analysis.

Total Speciated = Total mass (front plus back tube) of identified carbonyl compounds.

Total Unspeciated = Total mass (front plus back tube) of compounds characterized as carbonyl compounds but not identified as a specific compound because no analytical reference standard was available.

**Table G-3. Carbonyl Compounds (Speciated). Mass Emission Rates for Wood-Fired Boiler (SCC 10200902), Test #1 (August 8, 2000)**

Mass Fuel Consumed	= 97,690 kg
Total Volume of Combustion Air	= (combustion air flow rate) x (time) = (3,263.6 scfm) x (28.31685 sLpm/scfm) x (257.90 min) = 23,833,795 liters
Volume of Combustion Air Sampled	= (Venturi flow rate) x (time) = (17.19 sLpm) x (257.90 min) = 4,433.301 liters
Volume of Dilution Air	= (dilution air flow rate) x (time) = (822.4 sLpm) x (257.90 min) = 212,096.96 liters
Dilution Ratio	= (volume of dilution air + volume of combustion air)/volume of combustion air = (212,096.96 liters + 4,433.301 liters)/4,433.301 liters = 48.8
Mass Flow Rate of Carbonyls in Diluted Sample	= (mass carbonyls collected)/[(sample flow rate at cartridge) x (time)] = (53.0930 µg)/[(0.970699 Lpm) x (257.90 min)] = 0.2120808 µg/liter
Mass Flow Rate of Carbonyls in Undiluted Sample	= (mass flow rate carbonyls diluted) x dilution ratio = (0.2120808 µg/liter) x 48.841768* = 10.358401 µg/liter
Total Mass of Carbonyls in Sampled Air	= (mass flow rate of carbonyls in undiluted sample) x (volume of undiluted sample) = 10.358401 µg/liter x 4,433.301 liters = 45,921.91 µg
Total Carbonyls in Total Combustion Air	= [(mass of carbonyls in sampled air)/(volume of sampled air)] x (total combustion air) = [(45,921.91 µg)/(4,433.301 liters)] x (23,833,795 liters) = 246,880,011 µg
Mass Emission Rate of Speciated Carbonyls	= (mass carbonyls in total combustion air)/(kg fuel burned) = 246,880,011 µg /97,690 kg = 2,527.2 µg/kg fuel = 2.53 mg/kg fuel

\*Dilution factor is dimensionless

**Table G-4. Carbonyl Compounds (Speciated). Mass Emission Rates for Wood-Fired Boiler (SCC 10200902), Test #2 (August 9, 2000)**

Mass Fuel Consumed	= 127,027 kg
Total Volume of Combustion Air	= (combustion air flow rate) x (time) = (3,263.6 scfm) x (28.31685 sLpm/scfm) x (359.65 min) = 33,237,009 liters
Volume of Combustion Air Sampled	= (Venturi flow rate) x (time) = (17.06 sLpm) x (359.65 min) = 6,135.629 liters
Volume of Dilution Air	= (dilution air flow rate) x (time) = (823.46 sLpm) x (359.65 min) = 296,157.39 liters
Dilution Ratio	= (volume of dilution air + volume of combustion air)/volume of combustion air = (296,157.39 liters + 100,330,222 liters)/6,135.629 liters = 49.268464
Mass Flow Rate of Carbonyls in Diluted Sample	= (mass carbonyls collected)/[(sample flow rate at cartridge) x (time)] = (21.468 µg)/[(0.969695 Lpm) x (359.65 min)] = 0.0621336 µg/liter
Mass Flow Rate of Carbonyls in Undiluted Sample	= (mass flow rate carbonyls diluted) x dilution ratio = (0.0621336 µg/liter) x 49.268464* = 3.061223 µg/liter
Total Mass of Carbonyls in Sampled Air	= (mass flow rate of carbonyls in undiluted sample) x (volume of undiluted sample) = 3.061223 µg/liter x 6,135.629 liters = 18,782.53 µg
Total Carbonyls in Total Combustion Air	= [(mass of carbonyls in sampled air)/(volume of sampled air)] x (total combustion air) = [(18,782.53 µg)/(6,135.629 liters)] x (33,237,009 liters) = 101,745,906 µg
Mass Emission Rate of Speciated Carbonyls	= (mass carbonyls in total combustion air)/(kg fuel burned) = 101,745,906 µg /127,027 kg = 800.9786 µg/kg fuel = 0.801 mg/kg fuel

\*Dilution factor is dimensionless

**Table G-5. Carbonyl Compounds (Speciated + Unspeciated). Mass Emission Rates for Wood-Fired Boiler (SCC 10200902), Test #1 (August 8, 2000)**

Mass Fuel Consumed	= 97,690 kg
Total Volume of Combustion Air	= (combustion air flow rate) x (time) = (3,263.6 scfm) x (28.31685 sLpm/scfm) x (257.90 min) = 23,833,795 liters
Volume of Combustion Air Sampled	= (Venturi flow rate) x (time) = (17.19 sLpm) x (257.90 min) = 4,433.3 liters
Volume of Dilution Air	= (dilution air flow rate) x (time) = (822.4 sLpm) x (257.90 min) = 212,097.0 liters
Dilution Ratio	= (volume of dilution air + volume of combustion air)/volume of combustion air = (212,097.0 liters + 4,433.3 liters)/4,433.3 liters = 48.8
Mass Flow Rate of Carbonyls in Diluted Sample	= (mass carbonyls collected)/[(sample flow rate at cartridge) x (time)] = (57.6635 µg)/[(0.970699 Lpm) x (257.90 min)] = 0.2303 µg/liter
Mass Flow Rate of Carbonyls in Undiluted Sample	= (mass flow rate carbonyls diluted) x dilution ratio = (0.2303 µg/liter) x 48.8* = 11.25 µg/liter
Total Mass of Carbonyls in Sampled Air	= (mass flow rate of carbonyls in undiluted sample) x (volume of undiluted sample) = 11.25 µg/liter x 4,433.3 liters = 49,875.09 µg
Total Carbonyls in Total Combustion Air	= [(mass of carbonyls in sampled air)/(volume of sampled air)] x (total combustion air) = [(49,875.09 µg)/(4,433.3 liters)] x (23,833,795 liters) = 268,132,626 µg
Mass Emission Rate of Carbonyls (Speciated + Unspeciated)	= (mass carbonyls in total combustion air)/(kg fuel burned) = 268,132,626 µg /97,690 kg = 2,744.7 µg/kg fuel = 2.74 mg/kg fuel

\*Dilution factor is dimensionless

**Table G-6. Carbonyl Compounds (Speciated + Unspeciated). Mass Emission Rates for Wood-Fired Boiler (SCC 10200902), Test #2 (August 9, 2000)**

Mass Fuel Consumed	= 127,027 kg
Total Volume of Combustion Air	= (combustion air flow rate) x (time) = (3,263.6 scfm) x (28.31685 sLpm/scfm) x (359.65 min) = 33,237,008 liters
Volume of Combustion Air Sampled	= (Venturi flow rate) x (time) = (17.06 sLpm) x (359.65 min) = 6,135.6 liters
Volume of Dilution Air	= (dilution air flow rate) x (time) = (823.46 sLpm) x (359.65 min) = 296,157.4 liters
Dilution Ratio	= (volume of dilution air + volume of combustion air)/volume of combustion air = (296,157.4 liters + 6,135.6 liters)/6,135.6 liters = 49.3
Mass Flow Rate of Carbonyls in Diluted Sample	= (mass carbonyls collected)/[(sample flow rate at cartridge) x (time)] = (25.1195 µg)/[(0.960695 Lpm) x (359.65 min)] = 0.0727 µg/liter
Mass Flow Rate of Carbonyls in Undiluted Sample	= (mass flow rate carbonyls diluted) x dilution ratio = (0.0727 µg/liter) x 49.3* = 3.58 µg/liter
Total Mass of Carbonyls in Sampled Air	= (mass flow rate of carbonyls in undiluted sample) x (volume of undiluted sample) = 3.58 µg/liter x 6,135.6 liters = 21,997.26 µg
Total Carbonyls in Total Combustion Air	= [(mass of carbonyls in sampled air)/(volume of sampled air)] x (total combustion air) = [(21,997.26 µg)/(6,135.6 liters)] x 33,237,008 liters = 119,051,905 µg
Mass Emission Rate of Carbonyls (Speciated + Unspeciated)	= (mass carbonyls in total combustion air)/(kg fuel burned) = 119,051,905 µg /127,027 kg = 937.2 µg/kg fuel = 0.94 mg/kg fuel

\*Dilution factor is dimensionless

**Appendix H**

**Supporting Data for**  
**Speciated Nonmethane Organic Compound Analysis**

**Table H-1. Analytical Results for Field Samples, Speciated Nonmethane Organic Compounds, Test #1, 8/8/00**

	Compound	CAS No.	Blank	Dilution Air		Residence Chamber Air	
			µg/m <sup>3</sup>	µg/m <sup>3</sup>	Total µg	µg/m <sup>3</sup>	Total µg
	ethylene	74-85-1	0.15	1.65	350.0	14.69	3180.8
	acetylene	74-86-2	ND	0.87	184.5	9.4	2035.4
	ethane	74-84-0	0.17	2.76	585.4	6.96	1507.1
	propylene	115-07-1	0.09	57.24	12140.4	53.34	11549.7
	propane	74-98-6	0.18	51.97	11022.7	48.41	10482.2
	propyne	74-99-7	ND	ND	ND	ND	ND
	isobutane	75-28-5	0.09	0.68	144.2	1.51	327.0
	isobutene/1-butene	115-11-7/106-98-0	0.07	0.87	184.5	2.37	513.2
	1,3-butadiene	106-99-0	ND	ND	ND	0.31	67.1
	<i>n</i> -butane	106-97-8	0.15	0.85	180.3	1.56	337.8
	<i>trans</i> -2-butene	624-64-6	0.09	0.23	48.8	0.56	121.3
	<i>cis</i> -2-butene	590-18-1	0.12	0.43	91.2	0.67	145.1
	3-methyl-1-butene	563-45-1	ND	ND	ND	0.13	28.1
	isopentane	78-78-4	0.14	0.53	112.4	0.61	132.1
	1-pentene	109-67-1	ND	ND	ND	ND	ND
	2-methyl-1-butene	563-46-2	ND	ND	ND	0.16	34.6
	<i>n</i> -pentane	109-66-0	0.09	0.25	53.0	0.84	181.9
	isoprene	78-79-4	0.09	4.21	892.9	0.46	99.6
	<i>trans</i> -2-pentene	646-04-8	0.09	0.3	63.6	0.61	132.1
	<i>cis</i> -2-pentene	627-20-3	0.13	0.36	76.4	0.51	110.4
	2-methyl-2-butene	513-35-9	ND	ND	ND	ND	ND
	2,2-dimethylbutane	75-83-2	0.16	9.92	2104.0	5.45	1180.1
	cyclopentene	142-29-0	ND	0.22	46.7	0.23	49.8
	4-methyl-1-pentene	691-37-2	ND	ND	ND	ND	ND
	cyclopentane	287-92-3	0.09	0.37	78.5	0.4	86.6

ND = Compound not detected.

(Continued)



Table H-1. (Continued)

	Compound	CAS No.	Blank	Dilution Air		Residence Chamber Air	
			µg/m <sup>3</sup>	µg/m <sup>3</sup>	Total µg	µg/m <sup>3</sup>	Total µg
H-3	2,3-dimethylbutane	79-29-8	0.19	0.59	125.1	0.6	129.9
	2-methylpentane	107-83-5	0.08	0.54	114.5	ND	ND
	3-methylpentane	96-14-0	0.16	0.54	114.5	0.5	108.3
	2-methyl-1-pentene	763-29-1	ND	ND	ND	ND	ND
	1-hexene	592-41-6	0.21	0.68	144.2	1.58	342.1
	2-ethyl-1-butene	760-21-4	ND	ND	ND	ND	ND
	<i>n</i> -hexane	110-54-3	0.12	6.37	1351.1	2.18	472.0
	<i>trans</i> -2-hexene	4050-45-7	ND	ND	ND	ND	ND
	<i>cis</i> -2-hexene	7688-21-3	ND	ND	ND	ND	ND
	methylcyclopentane	96-37-7	0.11	0.87	184.5	0.65	140.7
	2,4-dimethylpentane	108-08-7	0.15	0.37	78.5	0.41	88.8
	benzene	71-43-2	0.12	0.35	74.2	400.2	86655.4
	cyclohexane	110-82-7	0.15	0.4	84.8	0.45	97.4
	2-methylhexane	591-76-4	0.07	0.92	195.1	0.22	47.6
	2,3-dimethylpentane	565-59-3	0.19	0.53	112.4	0.46	99.6
	3-methylhexane	589-34-4	0.12	1.14	241.8	0.96	207.9
	1-heptene	592-76-7	ND	0.15	31.8	ND	ND
	2,2,4-trimethylpentane	540-84-1	0.14	0.61	129.4	ND	ND
	<i>n</i> -heptane	142-82-5	0.12	0.67	142.1	1.51	327.0
	methylcyclohexane	108-87-2	0.14	7.92	1679.8	0.8	173.2
	2,2,3-trimethylpentane	564-02-3	ND	ND	ND	ND	ND
	2,3,4-trimethylpentane	565-75-3	0.1	0.36	76.4	0.5	108.3
	toluene	108-88-3	0.18	1.31	277.8	3.9	844.5
	2-methylheptane	592-27-8	0.1	0.44	93.3	0.42	90.9
	3-methylheptane	589-81-1	0.11	0.56	118.8	0.65	140.7

ND = Compound not detected.

(Continued)

Table H-1. (Continued)

	Compound	CAS No.	Blank	Dilution Air		Residence Chamber Air	
			µg/m <sup>3</sup>	µg/m <sup>3</sup>	Total µg	µg/m <sup>3</sup>	Total µg
H4	1-octene	111-66-0	ND	0.26	55.1	0.83	179.7
	<i>n</i> -octane	111-65-9	0.12	2.39	506.9	2.72	589.0
	ethylbenzene	100-41-4	0.1	1.01	214.2	1.36	294.5
	<i>m</i> -, <i>p</i> -xylene	108-38-3/106-42-3	0.15	1.21	256.6	1.7	368.1
	styrene	100-42-5	0.06	0.67	142.1	0.75	162.4
	<i>o</i> -xylene	95-47-6	0.1	0.63	133.6	ND	ND
	1-nonene	124-11-8	0.1	0.13	27.6	0.32	69.3
	<i>n</i> -nonane	111-84-2	0.15	0.81	171.8	1.34	290.2
	isopropylbenzene	98-82-8	0.3	0.33	70.0	0.42	90.9
	α-pinene	80-56-8	ND	4.77	1011.7	2.87	621.4
	<i>n</i> -propylbenzene	103-65-1	0.1	0.35	74.2	0.46	99.6
	<i>m</i> -ethyltoluene	620-14-4	0.18	1.52	322.4	1.43	309.6
	<i>p</i> -ethyltoluene	622-96-8	0.14	1.03	218.5	1.04	225.2
	1,3,5-trimethylbenzene	108-67-8	0.09	1.01	214.2	1.12	242.5
	<i>o</i> -ethyltoluene	611-14-3	0.1	2.57	545.1	2.58	558.6
	β-pinene	127-91-3	ND	2.07	439.0	1.84	398.4
	1,2,4-trimethylbenzene	95-63-6	0.15	1.44	305.4	1.8	389.9
	1-decene	872-05-9	ND	ND	ND	ND	ND
	<i>n</i> -decane	124-18-5	0.13	29.58	6273.8	28.75	6225.2
	1,2,3-trimethylbenzene	526-73-8	ND	0.4	84.8	0.51	110.4
	<i>m</i> -diethylbenzene	141-93-5	0.11	0.67	142.1	0.57	123.4
	<i>p</i> -diethylbenzene	105-05-5	0.1	0.24	50.9	0.2	43.3
	1-undecene	821-95-4	ND	ND	ND	ND	ND
	<i>n</i> -undecane	1120-21-4	0.14	4.48	950.2	4.44	961.4
	1-dodecene	112-41-4	ND	0.84	178.2	0.96	207.9

ND = Compound not detected.

(Continued)

**Table H-1. (Continued)**

Compound	CAS No.	Blank	Dilution Air		Residence Chamber Air	
		$\mu\text{g}/\text{m}^3$	$\mu\text{g}/\text{m}^3$	Total $\mu\text{g}$	$\mu\text{g}/\text{m}^3$	Total $\mu\text{g}$
<i>n</i> -dodecane	112-40-3	0.07	142.76	30279.0	142.42	30838.2
1-tridecene	2437-56-1	ND	0.82	173.9	1.04	225.2
<i>n</i> -tridecane	629-50-5	ND	0.84	178.2	0.9	194.9
Total Speciated		6.55	361.86	76749.4	767.54	166195.7
Total Unspeciated		6.37	77.02	16335.7	300.74	65119.3
Total Speciated + Unspeciated*		12.92	438.88	93085.1	1068.28	231315.0

\* Total NMOC with unknowns in  $\mu\text{g}/\text{m}^3$  is an estimate based on propane only.

ND = Not detected; compound not observed in the performance of the analysis.

NR = Not reported because of compound co-elution.

Total Speciated = Sum of concentrations for all identified peaks.

Total Unspeciated = Concentration obtained by taking the difference between (Total Speciated + Unspeciated) and Total Speciated.

Total Speciated + Unspeciated = Concentration obtained from the integration of all of the peaks in the chromatogram.

**Table H-2. Analytical Results for Field Samples, Speciated Nonmethane Organic Compounds, Test #2, 8/9/00**

	Compound	CAS No.	Blank	Dilution Air		Residence Chamber Air	
			µg/m <sup>3</sup>	µg/m <sup>3</sup>	Total µg	µg/m <sup>3</sup>	Total µg
H-6	ethylene	74-85-1	0.15	1.25	379.1	4.85	1466.1
	acetylene	74-86-2	ND	0.73	216.2	7.68	2321.6
	ethane	74-84-0	0.16	2.56	758.2	4.1	1239.4
	propylene	115-07-1	0.11	7.2	2132.3	10.02	3029.0
	propane	74-98-6	0.17	26.01	7703.1	25.96	7847.5
	propyne	74-99-7	ND	ND	ND	ND	ND
	isobutane	75-28-5	0.08	0.6	177.7	0.83	250.9
	isobutene/1-butene	115-11-7/106-98-0	0.07	0.52	154.0	1.04	314.4
	1,3-butadiene	106-99-0	ND	ND	ND	0.11	33.3
	<i>n</i> -butane	106-97-8	0.14	0.82	242.8	0.98	296.2
	<i>trans</i> -2-butene	624-64-6	0.08	0.27	80.0	ND	ND
	<i>cis</i> -2-butene	590-18-1	0.13	0.39	115.5	0.48	145.1
	3-methyl-1-butene	563-45-1	ND	ND	ND	ND	ND
	isopentane	78-78-4	0.14	0.48	142.2	0.5	151.1
	1-pentene	109-67-1	ND	ND	ND	ND	ND
	2-methyl-1-butene	563-46-2	ND	ND	ND	ND	ND
	<i>n</i> -pentane	109-66-0	0.09	0.5	148.1	0.94	284.2
	isoprene	78-79-4	0.12	1.42	420.5	0.4	120.9
	<i>trans</i> -2-pentene	646-04-8	0.10	0.26	77.0	0.35	105.8
	<i>cis</i> -2-pentene	627-20-3	0.13	0.35	103.7	0.41	123.9
	2-methyl-2-butene	513-35-9	ND	ND	ND	ND	ND
	2,2-dimethylbutane	75-83-2	0.16	1	296.2	1.08	326.5
	cyclopentene	142-29-0	ND	0.09	26.7	0.16	48.4
	4-methyl-1-pentene	691-37-2	ND	ND	ND	ND	ND
	cyclopentane	287-92-3	0.09	0.34	100.7	0.4	120.9

ND = Compound not detected.

(Continued)

Table H-2. (Continued)

	Compound	CAS No.	Blank	Dilution Air		Residence Chamber Air	
			µg/m <sup>3</sup>	µg/m <sup>3</sup>	Total µg	µg/m <sup>3</sup>	Total µg
H-7	2,3-dimethylbutane	79-29-8	0.2	0.53	157.0	0.54	163.2
	2-methylpentane	107-83-5	0.06	0.44	130.3	ND	ND
	3-methylpentane	96-14-0	0.17	0.58	171.8	0.52	157.2
	2-methyl-1-pentene	763-29-1	ND	ND	ND	ND	ND
	1-hexene	592-41-6	0.20	0.65	192.5	0.85	256.9
	2-ethyl-1-butene	760-21-4	ND	ND	ND	ND	ND
	<i>n</i> -hexane	110-54-3	0.12	8.83	2615.1	7.36	2224.9
	<i>trans</i> -2-hexene	4050-45-7	ND	ND	ND	ND	ND
	<i>cis</i> -2-hexene	7688-21-3	ND	ND	ND	ND	ND
	methylcyclopentane	96-37-7	0.10	1.18	349.5	1021	308641.2
	2,4-dimethylpentane	108-08-7	0.14	0.35	103.7	0.36	108.8
	benzene	71-43-2	0.12	0.48	142.2	100.45	30365.3
	cyclohexane	110-82-7	0.14	0.45	133.3	0.42	127.0
	2-methylhexane	591-76-4	0.07	0.66	195.5	0.56	169.3
	2,3-dimethylpentane	565-59-3	0.19	0.53	157.0	0.52	157.2
	3-methylhexane	589-34-4	0.14	0.48	142.2	0.51	154.2
	1-heptene	592-76-7	ND	0.12	35.5	ND	ND
	2,2,4-trimethylpentane	540-84-1	0.14	0.38	112.5	ND	ND
	<i>n</i> -heptane	142-82-5	0.11	0.35	103.7	0.45	136.0
	methylcyclohexane	108-87-2	0.14	0.73	216.2	0.64	193.5
	2,2,3-trimethylpentane	564-02-3	ND	0.12	35.5	ND	ND
	2,3,4-trimethylpentane	565-75-3	0.11	0.31	91.8	0.34	102.8
	toluene	108-88-3	0.20	1.04	308.0	1.92	580.4
	2-methylheptane	592-27-8	0.09	0.44	130.3	0.46	139.1
	3-methylheptane	589-81-1	0.11	0.32	94.8	0.36	108.8

ND = Compound not detected.

(Continued)

Table H-2. (Continued)

	Compound	CAS No.	Blank	Dilution Air		Residence Chamber Air	
			µg/m <sup>3</sup>	µg/m <sup>3</sup>	Total µg	µg/m <sup>3</sup>	Total µg
H-8	1-octene	111-66-0	ND	0.21	62.2	0.27	81.6
	<i>n</i> -octane	111-65-9	0.14	1.46	432.4	1.31	396.0
	ethylbenzene	100-41-4	0.12	1.4	414.6	1.37	414.1
	<i>m</i> -, <i>p</i> -xylene	108-38-3/106-42-3	0.17	3.81	1128.4	3.3	997.6
	styrene	100-42-5	0.08	1.12	331.7	0.95	287.2
	<i>o</i> -xylene	95-47-6	0.09	1.21	358.4	ND	ND
	1-nonene	124-11-8	ND	ND	ND	ND	ND
	<i>n</i> -nonane	111-84-2	0.10	0.95	281.4	0.98	296.2
	isopropylbenzene	98-82-8	0.16	0.32	94.8	0.33	99.8
	α-pinene	80-56-8	ND	0.41	121.4	1	302.3
	<i>n</i> -propylbenzene	103-65-1	0.10	0.48	142.2	0.36	108.8
	<i>m</i> -ethyltoluene	620-14-4	0.16	1.92	568.6	1.99	601.6
	<i>p</i> -ethyltoluene	622-96-8	0.13	1.06	313.9	1.04	314.4
	1,3,5-trimethylbenzene	108-67-8	0.10	1.01	299.1	0.85	256.9
	<i>o</i> -ethyltoluene	611-14-3	0.09	1.75	518.3	1.84	556.2
	β-pinene	127-91-3	ND	1.08	319.9	1.1	332.5
	1,2,4-trimethylbenzene	95-63-6	0.14	1.12	331.7	1.25	377.9
	1-decene	872-05-9	ND	ND	ND	ND	ND
	<i>n</i> -decane	124-18-5	0.15	26.48	7842.2	24.1	7285.3
	1,2,3-trimethylbenzene	526-73-8	ND	0.7	207.3	0.52	157.2
	<i>m</i> -diethylbenzene	141-93-5	0.13	0.61	180.7	0.57	172.3
	<i>p</i> -diethylbenzene	105-05-5	0.08	0.23	68.1	0.23	69.5
	1-undecene	821-95-4	ND	ND	ND	ND	ND
	<i>n</i> -undecane	1120-21-4	0.13	4.01	1187.6	3.61	1091.3
	1-dodecene	112-41-4	ND	0.96	284.3	0.95	287.2

ND = Compound not detected.

(Continued)

**Table H-2. (Continued)**

Compound	CAS No.	Blank	Dilution Air		Residence Chamber Air	
		µg/m <sup>3</sup>	µg/m <sup>3</sup>	Total µg	µg/m <sup>3</sup>	Total µg
<i>n</i> -dodecane	112-40-3	0.06	144.44	42777.0	124.54	37647.6
1-tridecene	2437-56-1	ND	0.79	234.0	ND	ND
<i>n</i> -tridecane	629-50-5	ND	0.75	222.1	0.48	145.1
Total Speciated		6.60	262.07	77614.0	350.7	75937.2
Total Unspeciated		6.46	48.66	14411.0	126.81	27458.2
Total Speciated + Unspeciated*		13.06	310.73	92025.0	477.51	103395.4

\*Total NMOC with unknowns in µg/m<sup>3</sup> is an estimate based on propane only.

ND = Not detected; compound not observed in the performance of the analysis.

NR = Not reported because of compound co-elution.

Total Speciated = Sum of concentrations for all identified peaks.

Total Unspeciated = Concentration obtained by taking the difference between (Total Speciated + Unspeciated) and Total Speciated.

Total Speciated + Unspeciated = Concentration obtained from the integration of all of the peaks in the chromatogram.

**Table H-3. Speciated Nonmethane Organic Compounds. Mass Emission Rates for Wood-Fired Boiler (SCC 10200902), Test #1 (August 8, 2000)**

---

Mass Fuel Consumed	=	97,690 kg
Total Volume of Combustion Air	=	(combustion air flow rate) x (time)
	=	(3,263.6 scfm) x (28.31685 sLpm/scfm) x (257.9 min)
	=	23,833,795 liters
Volume of Combustion Air Sampled	=	(Venturi flow rate) x (time)
	=	(17.19 sLpm) x (257.9 min)
	=	4,433.301 liters
Volume of Dilution Air	=	(dilution air flow rate) x (time)
	=	(822.4 sLpm) x (257.9 min)
	=	212,096.96 liters
Dilution Ratio	=	(volume of dilution air + volume of combustion air)/volume of combustion air
	=	(212,096.96 liters + 4,433.301 liters) / 4,433.301 liters
	=	48.8
Mass Flow Rate of SNMOC in Diluted Sample	=	(mass SNMOC collected)/[(sample flow rate at canister) x (time)]
	=	(1.862 µg)/[(0.0178 Lpm) x (257.9 min)]
	=	0.4056097 µg/liter
Mass Flow Rate of SNMOC in Undiluted Sample	=	(mass flow rate SNMOC diluted) x dilution ratio
	=	(0.4056097 µg/liter) x 48.8*
	=	19.810695 µg/liter
Total Mass of SNMOC in Sampled Air	=	(mass flow rate of SNMOC in undiluted sample) x (volume of undiluted sample)
	=	19.810695 µg/liter x 4,433.301 liters
	=	87826.774 µg
Total SNMOC in Total Combustion Air	=	[(mass of SNMOC in sampled air)/(volume of sampled air)] x (total combustion air)
	=	[(87826.774 µg)/(4,433.301 liters)] x 23,833,795 liters
	=	472,245,958 µg
Mass Emission Rate of Speciated SNMOC	=	(mass SNMOC in total combustion air)/(kg fuel burned)
	=	472,245,958 µg /97,690 kg
	=	4,834.1369 µg/kg fuel
	=	4.834 mg/kg fuel

---

\*Dilution factor is dimensionless.



**Table H-4. Speciated Nonmethane Organic Compounds. Mass Emission Rates for Wood-Fired Boiler (SCC 10200902), Test #2 (August 9, 2000)**

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Mass Fuel Consumed	=	127,027 kg
Total Volume of Combustion Air	=	(combustion air flow rate) x (time)
	=	(3,263.6 scfm) x (28.31685 sLpm/scfm) x (359.65 min)
	=	33,237,009 liters
Volume of Combustion Air Sampled	=	(Venturi flow rate) x (time)
	=	(17.06 sLpm) x (359.65 min)
	=	6,135.629 liters
Volume of Dilution Air	=	(dilution air flow rate) x (time)
	=	(823.46 sLpm) x (359.65 min)
	=	296,157.39 liters
Dilution Ratio	=	(volume of dilution air + volume of combustion air)/volume of combustion air
	=	(296,157.39 liters + 6,135.629 liters) / 6,135.629 liters
	=	49.3
Mass Flow Rate of SNMOC in Diluted Sample	=	(mass SNMOC collected)/[(sample flow rate at canister) x (time)]
	=	(0.918 µg)/[(0.0153 Lpm) x (359.65 min)]
	=	0.0761819 µg/liter
Mass Flow Rate of SNMOC in Undiluted Sample	=	(mass flow rate SNMOC diluted) x dilution ratio
	=	(0.0761819 µg/liter) x 49.3*
	=	3.753 µg/liter
Total Mass of SNMOC in Sampled Air	=	(mass flow rate of SNMOC in undiluted sample) x (volume of undiluted sample)
	=	3.753 µg/liter x 6,135.629 liters
	=	23,029.26 µg
Total SNMOC in Total Combustion Air	=	[(mass of SNMOC in sampled air)/(volume of sampled air)] x (total combustion air)
	=	[(23,029.26 µg)/(6,135.629 liters)] x 33,237,009 liters
	=	124,750,631 µg
Mass Emission Rate of Speciated SNMOC	=	(mass SNMOC in total combustion air)/(kg fuel burned)
	=	124,750,631 µg /127,027 kg
	=	982.080 µg/kg fuel
	=	0.982 mg/kg fuel

---

\*Dilution factor is dimensionless.

**Table H-5. Calculation of Mass Emission Rate for Speciated + Unspeciated Nonmethane Organic Compounds for a Wood-Fired Boiler (SCC 10200902), Test #1**

Mass Fuel Consumed	= 97,690 kg
Total Volume of Combustion Air	= (combustion air flow rate) x (time) = (3,263.6 scfm) x (28.31685 sLpm/scfm) x (257.90 min) = 23,833,795 liters
Volume of Combustion Air Sampled	= (Venturi flow rate) x (time) = (17.19 sLpm) x (257.90 min) = 4,433.3 liters
Volume of Dilution Air	= (dilution air flow rate) x (time) = (822.4 sLpm) x (257.90 min) = 212,097.0 liters
Dilution Ratio	= (volume of dilution air + volume of combustion air)/volume of combustion air = (212,097.0 liters + 4,433.3 liters)/4,433.3 liters = 48.8
Mass Flow Rate of SNMOC in Diluted Sample	= (mass SNMOC collected)/[(sample flow rate at canister) x (time)] = (2.889336 µg)/[(0.0178 Lpm) x (257.90 min)] = 0.6294 µg/liter
Mass Flow Rate of SNMOC in Undiluted Sample	= (mass flow rate SNMOC diluted) x dilution ratio = (0.6294 µg/liter) x 48.8* = 30.7410 µg/liter
Total Mass of SNMOC in Sampled Air	= (mass flow rate of SNMOC in undiluted sample) x (volume of undiluted sample) = 30.7410 µg/liter x 4,433.3 liters = 136,284.15 µg
Total SNMOC in Total Combustion Air	= [(mass of SNMOC in sampled air)/(volume of sampled air)] x (total combustion air) = [(136,284.15 µg)/4,433.3 liters] x (23,833,795 liters) = 732,674,863 µg
Mass Emission Rate of SNMOC (Speciated + Unspeciated)	= (mass SNMOC in total combustion air)/(kg fuel burned) = 732,674,863 µg /97,690 kg = 7500.0125 µg/kg fuel = 7.500 mg/kg fuel

\*Dilution factor is dimensionless.

**Table H-6. Calculation of Mass Emission Rate for Speciated + Unspeciated Nonmethane Organic Compounds for a Wood-Fired Boiler (SCC 10200902), Test #2**

Mass Fuel Consumed	= 127,027 kg
Total Volume of Combustion Air	= (combustion air flow rate) x (time) = (3,263.6 scfm) x (28.31685 sLpm/scfm) x (359.65 min) = 33,237,009 liters
Volume of Combustion Air Sampled	= (Venturi flow rate) x (time) = (17.06 sLpm) x (359.65 min) = 6,135.6 liters
Volume of Dilution Air	= (dilution air flow rate) x (time) = (823.46 sLpm) x (359.65 min) = 296,157.4 liters
Dilution Ratio	= (volume of dilution air + volume of combustion air)/volume of combustion air = (296,157.4 liters + 6,135.6 liters)/6,135.6 liters = 49.3
Mass Flow Rate of SNMOC in Diluted Sample	= (mass SNMOC collected)/[(sample flow rate at canister) x (time)] = (0.917731 µg)/[(0.0153 Lpm) x (359.65 min)] = 0.14336 µg/liter
Mass Flow Rate of SNMOC in Undiluted Sample	= (mass flow rate SNMOC diluted) x dilution ratio = (0.14336 µg/liter) x 49.3* = 7.06292 µg/liter
Total Mass of SNMOC in Sampled Air	= (mass flow rate of SNMOC in undiluted sample) x (volume of undiluted sample) = 7.06292 µg/liter x 6,135.6 liters = 43,335.46 µg
Total SNMOC in Total Combustion Air	= [(mass of SNMOC in sampled air)/(volume of sampled air)] x (total combustion air) = [(43,335.46 µg)/(6,135.6 liters)] x 33,237,009 liters = 234,750,372 µg
Mass Emission Rate of SNMOC (Speciated + Unspeciated)	= (mass SNMOC in total combustion air)/(kg fuel burned) = 234,750,372 µg /127,027 kg = 1848.035 µg/kg fuel = 1.848 mg/kg fuel

\*Dilution factor is dimensionless.

## **Appendix I**

### **Data from the Scanning Mobility Particle Sizer**

# TSI Scanning Mobility Particle Sizer

FILENAME: 8-8TST.005	SCAN VOLTAGE: 10 V, 9748 V
NOTEFILE:	SCAN RANGE: 9.31 nm to 421.70 nm
RESOLUTION: 32 channels/decade	VIEW RANGE: 10.00 nm to 392.42 nm
SAMPLE TIME: 12:58:31	tf: 3.7 s, td: 0.6 s
SAMPLE DATE: Tue 8 Aug 2000	tup: 120.0 s, tdwn: 30.0 s
SAMPLE No: 1, SCANS/SAMPLE: 107	Qsh: 6.0 lpm, Qa: 0.6 lpm
CHARGE CORRECTION: off	IMPACTOR D50: 458 nm

Particle Size Statistics:		No Assumption(1)	Lognormal Assumption(2)
Number Count:			
median (nm)	106.616	106.616	
mean (nm)	122.413	141.164	
geometric mean (nm)	96.366		
mode (nm)	128.640	60.816	
standard deviation	78.125		
geo. standard deviation	2.115	2.115	
skewness	-0.080		
coeff. of variation (%)	63.821		
Total Concentration (#/cm3)	5.1057E+04		
Surface Area:			
median (nm)	210.401	327.667	
mean (nm)	211.591		
geometric mean (nm)	194.017	433.846	
mode (nm)	245.824		
standard deviation	79.670		
geo. standard deviation	1.565		
dia. of average surface (nm)		186.908	
Total Concentration (nm2/cm3)	3.3826E+09		
Volume:			
median	242.954	574.432	
mean	241.589		
geometric mean	228.085	760.574	
mode	264.165		
standard deviation	74.778		
geo. standard deviation	1.434		
dia. of average volume (nm)		247.474	
Total Concentration (nm3/cm3)	1.1929E+11		

1 The statistics in 'No Assumptions' column are calculated based on the number size distribution. The validity of the statistics depends on the completeness of the distribution as well as the appropriateness of the calculation. For example: standard deviation and geometric standard deviation cannot both be valid since they are appropriate only for normal and lognormal distributions, respectively.

2 The statistics in the 'Lognormal Assumption' are calculated based on the number median and geometric standard deviation of the sampled data. The remaining values are derived from the Hatch-Choate conversion equations for lognormal distributions.

# TSI Scanning Mobility Particle Sizer

FILENAME: 8-8TST.005	SCAN VOLTAGE: 10 V, 9748 V
NOTEFILE:	SCAN RANGE: 9.31 nm to 421.70 nm
RESOLUTION: 32 channels/decade	VIEW RANGE: 10.00 nm to 392.42 nm
SAMPLE TIME: 12:58:31	tf: 3.7 s, td: 0.6 s
SAMPLE DATE: Tue 8 Aug 2000	tup: 120.0 s, tdwn: 30.0 s
SAMPLE No: 1, SCANS/SAMPLE: 107	Qsh: 6.0 lpm, Qa: 0.6 lpm
CHARGE CORRECTION: off	IMPACTOR D50: 458 nm

Conc. [d(N,S,V)/dlog(Dp)] - Base data

Channel number	Midpoint diameter (nanometers)	CONCENTRATION		
		Number (# /cm3)	Surface (nm2 / cm3)	Volume (nm3 / cm3)
32	10.37	4.5569E+03	1.5384E+06	2.6579E+06
33	11.14	4.5236E+03	1.7635E+06	3.2742E+06
34	11.97	5.1825E+03	2.3331E+06	4.6549E+06
35	12.86	5.1946E+03	2.7006E+06	5.7900E+06
36	13.82	5.6878E+03	3.4146E+06	7.8671E+06
37	14.86	6.1452E+03	4.2602E+06	1.0548E+07
38	15.96	6.8709E+03	5.5006E+06	1.4635E+07
39	17.15	7.7160E+03	7.1333E+06	2.0395E+07
40	18.43	8.1688E+03	8.7208E+06	2.6794E+07
41	19.81	9.4522E+03	1.1653E+07	3.8473E+07
42	21.29	1.0769E+04	1.5331E+07	5.4394E+07
43	22.88	1.1672E+04	1.9188E+07	7.3158E+07
44	24.58	1.2838E+04	2.4371E+07	9.9852E+07
45	26.42	1.5840E+04	3.4726E+07	1.5289E+08
46	28.39	1.6109E+04	4.0782E+07	1.9295E+08
47	30.51	1.7367E+04	5.0773E+07	2.5814E+08
48	32.78	1.9013E+04	6.4189E+07	3.5070E+08
49	35.23	2.0555E+04	8.0133E+07	4.7048E+08
50	37.86	2.3000E+04	1.0354E+08	6.5328E+08
51	40.68	2.4900E+04	1.2945E+08	8.7766E+08
52	43.71	2.8154E+04	1.6902E+08	1.2314E+09
53	46.98	3.0985E+04	2.1481E+08	1.6818E+09
54	50.48	3.4716E+04	2.7793E+08	2.3383E+09
55	54.25	3.8191E+04	3.5307E+08	3.1922E+09
56	58.29	4.0189E+04	4.2905E+08	4.1686E+09
57	62.64	4.4154E+04	5.4434E+08	5.6832E+09
58	67.32	4.6956E+04	6.6849E+08	7.5001E+09
59	72.34	4.9890E+04	8.2019E+08	9.8886E+09
60	77.74	5.1283E+04	9.7358E+08	1.2614E+10
61	83.54	5.2677E+04	1.1548E+09	1.6078E+10
62	89.77	5.3890E+04	1.3643E+09	2.0412E+10
63	96.47	5.7513E+04	1.6814E+09	2.7033E+10
64	103.66	5.9258E+04	2.0005E+09	3.4564E+10
65	111.40	6.1053E+04	2.3801E+09	4.4190E+10
66	119.71	6.1970E+04	2.7898E+09	5.5661E+10
67	128.64	6.3754E+04	3.3144E+09	7.1061E+10
68	138.24	6.3446E+04	3.8089E+09	8.7756E+10
69	148.55	6.2829E+04	4.3557E+09	1.0784E+11
70	159.63	6.2378E+04	4.9938E+09	1.3286E+11
71	171.54	6.0367E+04	5.5808E+09	1.5956E+11

# TSI Scanning Mobility Particle Sizer

FILENAME: 8-8TST.005	SCAN VOLTAGE: 10 V, 9748 V
NOTEFILE:	SCAN RANGE: 9.31 nm to 421.70 nm
RESOLUTION: 32 channels/decade	VIEW RANGE: 10.00 nm to 392.42 nm
SAMPLE TIME: 12:58:31	tf: 3.7 s, td: 0.6 s
SAMPLE DATE: Tue 8 Aug 2000	tup: 120.0 s, tdwn: 30.0 s
SAMPLE No: 1, SCANS/SAMPLE: 107	Qsh: 6.0 lpm, Qa: 0.6 lpm
CHARGE CORRECTION: off	IMPACTOR D50: 458 nm

Conc. [d(N,S,V)/dlog(Dp)] - Base data

Channel number	Midpoint diameter (nanometers)	CONCENTRATION		
		Number (# /cm3)	Surface (nm2 / cm3)	Volume (nm3 / cm3)
71	171.54	6.0367E+04	5.5808E+09	1.5956E+11
72	184.34	5.7673E+04	6.1570E+09	1.8917E+11
73	198.10	5.6045E+04	6.9094E+09	2.2812E+11
74	212.88	5.3459E+04	7.6106E+09	2.7002E+11
75	228.76	4.8207E+04	7.9251E+09	3.0216E+11
76	245.82	4.2193E+04	8.0101E+09	3.2818E+11
77	264.16	3.5734E+04	7.8339E+09	3.4491E+11
78	283.87	2.7981E+04	7.0837E+09	3.3515E+11
79	305.05	2.2023E+04	6.4385E+09	3.2735E+11
80	327.81	1.4979E+04	5.0570E+09	2.7629E+11
81	352.27	1.0229E+04	3.9878E+09	2.3413E+11
82	378.55	6.0963E+03	2.7445E+09	1.7316E+11
		5.1057E+04	3.3826E+09	1.1929E+11

# TSI Scanning Mobility Particle Sizer

FILENAME: 8-9TST.002	SCAN VOLTAGE: 10 V, 9748 V
NOTEFILE:	SCAN RANGE: 9.31 nm to 421.70 nm
RESOLUTION: 32 channels/decade	VIEW RANGE: 10.00 nm to 392.42 nm
SAMPLE TIME: 09:08:54	tf: 3.7 s, td: 0.6 s
SAMPLE DATE: Wed 9 Aug 2000	tup: 120.0 s, tdwn: 30.0 s
SAMPLE No: 1, SCANS/SAMPLE: 145	Qsh: 6.0 lpm, Qa: 0.6 lpm
CHARGE CORRECTION: off	IMPACTOR D50: 458 nm

Particle Size Statistics:		No Assumption(1)	Lognormal Assumption(2)
Number Count:			
median (nm)		146.075	146.075
mean (nm)		157.554	173.687
geometric mean (nm)		136.453	
mode (nm)		159.634	103.322
standard deviation		77.155	
geo. standard deviation		1.801	1.801
skewness		-0.027	
coeff. of variation (%)		48.970	
Total Concentration (#/cm3)		4.2470E+03	
Surface Area:			
median (nm)		222.565	291.971
mean (nm)		227.765	
geometric mean (nm)		212.504	347.161
mode (nm)		264.165	
standard deviation		79.502	
geo. standard deviation		1.477	
dia. of average surface (nm)			206.518
Total Concentration (nm2/cm3)		4.1063E+08	
Volume:			
median		257.948	412.784
mean		255.516	
geometric mean		242.590	490.811
mode		305.053	
standard deviation		76.281	
geo. standard deviation		1.402	
dia. of average volume (nm)			245.555
Total Concentration (nm3/cm3)		1.5588E+10	

1 The statistics in 'No Assumptions' column are calculated based on the number size distribution. The validity of the statistics depends on the completeness of the distribution as well as the appropriateness of the calculation. For example: standard deviation and geometric standard deviation cannot both be valid since they are appropriate only for normal and lognormal distributions, respectively.

2 The statistics in the 'Lognormal Assumption' are calculated based on the number median and geometric standard deviation of the sampled data. The remaining values are derived from the Hatch-Choate conversion equations for lognormal distributions.



# TSI Scanning Mobility Particle Sizer

FILENAME: 8-9TST.002	SCAN VOLTAGE: 10 V, 9748 V
NOTEFILE:	SCAN RANGE: 9.31 nm to 421.70 nm
RESOLUTION: 32 channels/decade	VIEW RANGE: 10.00 nm to 392.42 nm
SAMPLE TIME: 09:08:54	tf: 3.7 s, td: 0.6 s
SAMPLE DATE: Wed 9 Aug 2000	tup: 120.0 s, tdwn: 30.0 s
SAMPLE No: 1, SCANS/SAMPLE: 145	Qsh: 6.0 lpm, Qa: 0.6 lpm
CHARGE CORRECTION: off	IMPACTOR D50: 458 nm

Conc: [d(N,S,V)/dlog(Dp)] - Base data

Channel number	Midpoint diameter (nanometers)	CONCENTRATION		
		Number (# /cm3)	Surface (nm2 / cm3)	Volume (nm3 / cm3)
3)	10.37	6.1826E+01	2.0872E+04	3.6061E+04
3)	11.14	1.4589E+02	5.6874E+04	1.0559E+05
3)	11.97	8.8804E+01	3.9979E+04	7.9764E+04
3)	12.86	1.4405E+02	7.4887E+04	1.6056E+05
3)	13.82	1.8591E+02	1.1161E+05	2.5715E+05
3)	14.86	2.9475E+02	2.0434E+05	5.0591E+05
3)	15.96	2.2742E+02	1.8206E+05	4.8439E+05
3)	17.15	2.6769E+02	2.4748E+05	7.0756E+05
4)	18.43	2.1454E+02	2.2904E+05	7.0369E+05
4)	19.81	2.1332E+02	2.6298E+05	8.6826E+05
4)	21.29	3.3789E+02	4.8103E+05	1.7067E+06
4)	22.88	3.0047E+02	4.9398E+05	1.8834E+06
4)	24.58	3.8752E+02	7.3570E+05	3.0142E+06
4)	26.42	3.1271E+02	6.8556E+05	3.0184E+06
4)	28.39	3.1644E+02	8.0111E+05	3.7902E+06
4)	30.51	3.7706E+02	1.1023E+06	5.6044E+06
4)	32.78	4.2752E+02	1.4433E+06	7.8855E+06
4)	35.23	5.0509E+02	1.9691E+06	1.1561E+07
5)	37.86	7.3758E+02	3.3205E+06	2.0950E+07
5)	40.68	6.8136E+02	3.5422E+06	2.4016E+07
5)	43.71	7.5086E+02	4.5078E+06	3.2842E+07
5)	46.98	7.4023E+02	5.1318E+06	4.0178E+07
5)	50.48	9.4686E+02	7.5803E+06	6.3776E+07
5)	54.25	1.2043E+03	1.1133E+07	1.0066E+08
5)	58.29	1.2382E+03	1.3219E+07	1.2843E+08
5)	62.64	1.4787E+03	1.8230E+07	1.9033E+08
5)	67.32	1.7411E+03	2.4787E+07	2.7810E+08
5)	72.34	2.2113E+03	3.6354E+07	4.3830E+08
6)	77.74	2.6765E+03	5.0813E+07	6.5833E+08
6)	83.54	3.4839E+03	7.6378E+07	1.0634E+09
6)	89.77	3.8691E+03	9.7951E+07	1.4655E+09
6)	96.47	4.9400E+03	1.4442E+08	2.3219E+09
6)	103.66	5.9773E+03	2.0179E+08	3.4864E+09
6)	111.40	6.4918E+03	2.5309E+08	4.6988E+09
6)	119.71	6.7091E+03	3.0204E+08	6.0261E+09
6)	128.64	7.2795E+03	3.7844E+08	8.1138E+09
6)	138.24	7.8915E+03	4.7376E+08	1.0915E+10
6)	148.55	7.8599E+03	5.4490E+08	1.3491E+10
7)	159.63	8.1725E+03	6.5427E+08	1.7407E+10
7)	171.54	7.4512E+03	6.8885E+08	1.9695E+10

# TSI Scanning Mobility Particle Sizer

FILENAME: 8-9TST.002

NOTEFILE:

RESOLUTION: 32 channels/decade

SAMPLE TIME: 09:08:54

SAMPLE DATE: Wed 9 Aug 2000

SAMPLE No: 1, SCANS/SAMPLE: 145

CHARGE CORRECTION: off

SCAN VOLTAGE: 10 V, 9748 V

SCAN RANGE: 9.31 nm to 421.70 nm

VIEW RANGE: 10.00 nm to 392.42 nm

tf: 3.7 s, td: 0.6 s

tup: 120.0 s, tdwn: 30.0 s

Qsh: 6.0 lpm, Qa: 0.6 lpm

IMPACTOR D50: 458 nm

Conc. [d(N,S,V)/dlog(Dp)] - Base data

Channel number	Midpoint diameter (nanometers)	CONCENTRATION		
		Number (# /cm3)	Surface (nm2 / cm3)	Volume (nm3 / cm3)
71	171.5	7.4512E+03	6.8885E+08	1.9695E+10
72	184.3	7.0760E+03	7.5542E+08	2.3209E+10
73	198.1	6.7181E+03	8.2823E+08	2.7345E+10
74	212.8	6.1852E+03	8.8055E+08	3.1241E+10
75	228.7	5.2374E+03	8.6102E+08	3.2828E+10
76	245.8	4.7803E+03	9.0752E+08	3.7182E+10
77	264.1	4.2269E+03	9.2666E+08	4.0799E+10
78	283.8	3.6308E+03	9.1920E+08	4.3489E+10
79	305.0	3.0688E+03	8.9716E+08	4.5614E+10
80	327.8	2.3582E+03	7.9611E+08	4.3496E+10
81	352.2	1.8652E+03	7.2715E+08	4.2692E+10
82	378.5	1.4157E+03	6.3732E+08	4.0210E+10
Totals		4.2470E+03	4.1063E+08	1.5588E+10